TECHNICAL BULLETIN 33 JANUARY 1926

University of Minnesota
Agricultural Experiment Station

A Genetic and Cytological Study of Dwarfing in Wheat and Oats

Cyril H. Goulden
Division of Agronomy and Farm Management

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	3
Review of literature	3
Materials and methods	5
Wheat dwarfs	6
Dwarfing in a Kota-Marquis cross	6
Dwarfing in a Chul-Marquis cross	14
Cytological studies	16
Interpretation of chromosome behavior	17
Application of chromosome behavior to breeding behavior of progeny of Kota-Marquis and Chul-Marquis crosses	20
Discussion	26
An oat dwarf	28
History and breeding behavior	28
Cytological studies	33
Discussion	34
Summary	34
Literature cited	36

ILLUSTRATIONS

	Page
Fig. 1. F_1 of the Backcrosses as grown in the greenhouse, 1924-25	15
Fig. 2. Graphic representation of summarized data from Table XX	31
Fig. 3. Frequency distribution on a percentage basis for height of tallest culm for false wild, intermediate, and cultivated classes in the F_2 of a cross between false wild and cultivated	32
Fig. 4. Frequency distribution on a percentage basis for average height of culm for the false wild, intermediate and cultivated classes in the F_2 of a cross between false wild and cultivated	32
Plates	38

UNIVERSITY OF ARIZONA
630.72
M66b
LIBRARY

A GENETIC AND CYTOLOGICAL STUDY OF DWARFING IN WHEAT AND OATS[1]

By CYRIL H. GOULDEN[2]

INTRODUCTION

The inheritance of dwarfing has been studied in corn, cotton, obacco, peas, beans, wheat, oats, barley, and a number of other plants. n many cases the results obtained have been explainable on a straight actor basis, but in some instances, particularly with wheat, the mode f inheritance of dwarfing has been found to be very irregular, and ne investigators have failed to advance a complete and satisfactory xplanation of the phenomena observed. A fairly complete review of ne literature of the subject has been made by Waldron (*27*). It will e necessary to review here only the latter paper and a few others vhich have been published more recently or have a direct bearing on the nore recent studies.

REVIEW OF LITERATURE

Extensive data on the inheritance of dwarfing in a Kota-Marquis ross have been presented by Waldron (*27*). The F_1 plants were all ormal, and in the F_2 generation there were 229 normals to 47 dwarfs. The largest amount of data was obtained from the F_3 generation of ne F_2 family, No. 149. The F_3 lines were grouped and fitted to the earest Mendelian ratio. In this way it was found that the ratio roups 3:1, 13:3, 55:9, 15:1, and 63:1 were represented. That nese groups could be obtained does not offer a solution of the prob- em, as all of the different groups would not be represented if definite actors are responsible for the character, and the process of segrega- on is normal. Furthermore, the number of individuals in each family, vhile normally as large as could be expected, was not large enough o justify the differentiation made between 3:1 and 13:3 ratios or etween 13:3 and 55:9 ratios. Again, the separation of the actual atios into their respective ratio groups seems not to have been carried ut on a statistical basis.

[1] Submitted to the faculty of the Graduate School, University of Minnesota, in partial lfillment of the requirements for the degree of Doctor of Philosophy, June, 1925.

[2] The investigation was conducted under the direction of Dr. H. K. Hayes, Professor of ant Breeding, University of Minnesota, to whom the author is indebted for valuable sug- stions in conducting the investigation and for assistance in planning the method of presenting e results and conclusions. The author is also indebted to Dr. Fred Griffee, assistant pro- ssor of plant breeding, under whose direction the cytological work was done, and to r. W. P. Thompson of the University of Saskatchewan for some of the material and data ilized in the study.

81453

In order to explain the results, Waldron advances a three-factor hypothesis. One of the factors is the normal factor N and the other two are complementary dwarf factors, A and D, which are inhibited by N. This hypothesis does not account for all of the F_3 ratios obtained, so it is suggested in addition that the genes concerned are in a labile condition, often changing from dwarf genes to normal and vice versa. The explanation does not seem to be entirely satisfactory and the difficulty of its proof is appreciated by the author in the statement that "the labile condition of the genes will greatly handicap a demonstration of the hypothesis."

A dwarf which appeared in Marquis wheat has been described by Thompson (26). The dwarf condition is dominant to tallness and can not be obtained in a homozygous condition. The ratios obtained from segregating dwarfs indicate that the dwarf character is not due to a single genetic factor. A preliminary cytological examination of root tip cells of the dwarf indicated that only about 20 chromosomes were present, while in normal material the chromosome number is 42.

From a *Triticum polonicum* x *T. spelta* cross, Kihara (15) obtained 41-chromosome plants in the F_2 generation, some of which gave rise to dwarf plants in the F_3 which possessed only 40 chromosomes. These dwarf plants bred true for type and were constant for chromosome number. They belonged to the class designated by the author as sterile combinations, since the chromosome complement could be represented by the formula 20^b+0^i, where $20^b=20$ bivalents and $0^i=0$ univalents. In the progeny of one 41-chromosome plant there appeared 53 dwarfs of the 40-chromosome type and 459 normal plants. A 40-chromosome race was found in the progeny of another pentaploid hybrid and was semi-dwarfed in habit.

Winge (30) described a dwarf club wheat which was much-branched, late maturing, and possessed an ear that resembled the Square-Head type. Certain dwarf plants produced progeny which segregated in a 3:1 ratio of dwarfs to normals, while the progeny of another class of dwarfs segregated in a 1:1 ratio. A cytological study of the dwarfs giving progeny which segregated in a 3:1 ratio of dwarfs to normals showed its chromosome complement to be normal as regards number, but an occasional lagging chromosome was observed, indicating that the type must be regarded as unbalanced. "Stellenweise ist ausserdem dass Entstehen eines Vagabundenchromosoms beobachtet worden, und auch dies zeigt dass der Typus trotz allem als 'unbalanced' betrachtet werden muss." The dwarf giving progeny which segregate in a 1:1 ratio was not studied cytologically.

Warburton (28) reported a dwarf oat which appeared as a mutant form in the Victory variety. Breeding tests of the Victory dwarf

ndicated that it was a simple recessive to normal habit of growth.

In the progeny of a selection from a cross between Aurora and Pringless Progress varieties of oats, Stanton (25) noted 8 plants of an early prolific dwarf. Further studies tended to show that the dwarf condition was dominant. Another dwarf which appeared to behave in a similar manner was obtained from a cross of Winter Turf × Sixty Day. This dwarf was also early and prolific.

MATERIALS AND METHODS

Material from two crosses was used in this study. The Kota-Marquis material was from a cross which had been studied previously by Hayes and Aamodt (10) in 1923. The data on the F_1 and F_2 generations of this cross were taken directly from their 1923 publication. The Chul-Marquis cross was made by Dr. W. P. Thompson, of the University of Saskatchewan, who was kind enough to turn over this material when the writer was leaving that institution in the fall of 1923. The F_1 and part of the F_2 data were furnished by Dr. Thompson.

During the summer of 1924, F_3 material of the Kota-Marquis cross and the F_2 and F_3 material of the Chul-Marquis cross were grown in the plant breeding nursery at University Farm, St. Paul. It was grown in the usual plant rows which are five feet long and in each of which 75 seeds were planted. All of the F_2 material available was grown and as much as possible of the F_3. The F_3 families were grown from F_2 plants selected at random and when possible 50 to 75 seeds of each were sown. At harvest the plants were classified into dwarfs and normals on the basis of their height and general habit of growth. It is very difficult to make a clear-cut distinction between normals and dwarfs on the basis of their height alone, as normal plants are often stunted from disease or unfavorable soil conditions; and heterozygous dwarfs when grown under unusually favorable conditions, while typically dwarfed at the base, send up one or two culms which may attain normal height. For this reason, altho the height of the plants was always taken, a notation was made as to whether the growth habit of the plants was normal or dwarfed. This practically amounts to classification on the basis of general appearance and disregards the height.

In calculating the goodness of fit of the ratios obtained, the tables of probable errors of Mendelian ratios prepared by the Department of Plant Breeding, Cornell University, were used. The probable errors in these tables are calculated from the usual formula $0.6744898 \sqrt{p.q.n.}$ where n=the number of individuals and p and q are the percentages corresponding to the ratio concerned. Since the probable error method of testing the goodness of fit of Mendelian ratios was first used by Velden (29) and Johannsen (11), there has been some doubt in the

minds of geneticists as to its applicability in certain cases. The chief difficulties have been pointed out by Harris (9) and Pearl (16) and these have been kept in mind here in drawing conclusions from the results. Since the ratios dealt with are in most cases 3:1 or 13:3, there is no particular objection to the method except where only small numbers are available. It seems much better, however, to calculate the goodness of fit for all the ratios obtained and to use judgment in drawing conclusions than to use the probable error method only for those cases where large numbers are available.

WHEAT DWARFS

DWARFING IN A KOTA-MARQUIS CROSS

Breeding behavior in F_1 and F_2 generations.—As previously reported by Hayes and Aamodt (10), the F_1 plants of this cross were quite normal. In the F_2 generation dwarf plants appeared. It was pointed out that the ratio of normals to dwarfs was approximately 13:3 and that this could be explained on a two-factor basis, an inhibitor and a dominant dwarf factor. One of the parents would be homozygous for both dominant factors while the other would be homozygous for both recessive allelomorphs. The F_2 data are reproduced in Table I and fitted to a theoretical 13:3 ratio.

TABLE I

SEGREGATION IN F_2 OF KOTA-MARQUIS CROSS, FOR NORMALS AND DWARFS, AND CALCULATION OF GOODNESS OF FIT TO A 13:3 RATIO

	Actual	Theoretical (13:3)	Dev.	P.E.	Dev./P.E.
Normal	666	639.4	26.6	7.39	3.6
Dwarf	121	147.5			
			Odds=64.79:1		

The odds against the occurrence of such a deviation due to random sampling are 64.79:1 and indicate the possibility of a better fit to a 55:9 ratio. That this is actually the case is shown in Table II.

TABLE II

F_2 DATA FROM TABLE I FITTED TO A 55:9 RATIO

	Actual	Theoretical (55:9)	Dev.	P.E.	Dev./P.E.
Normal	666	676.3	10.3	6.58	1.6
Dwarf	121	110.7			
			Odds=2.57:1		

Here the odds are only 2.57:1 against the occurrence of such a deviation due to random sampling. On this basis it would be necessary to assume the presence of a second dwarf factor complementary

to the first in order to explain the results, but, as will be shown later, there are reasons to believe that this is merely a rather wide deviation from a 13:3 ratio.

Breeding behavior in F_2 generation.—In the F_2 generation 109 families were grown. Of these 85 were from normal F_2 plants and the remaining 24 were from dwarfs. In both cases random selection was practiced in order that the proportions of true breeding and segregating families could be compared with the theoretical proportions.

Before proceeding to a further discussion of the results, the expected behavior in F_1, F_2, and F_3 according to the above mentioned factor hypotheses will be outlined.

Two-Factor Hypothesis

D=dominant dwarf factor
I =inhibitor. Plants are always normal when this factor is present.

P_1	Parents.....	IIDD	x iidd	Both normal
F_1		IiDd		Normal

F_2

Phenotype and Frequency	Genotype Frequency	Genotypes	Behavior in F_3
Normal 13	1	IIDD	Breeds true
	2	IiDD	3 normal : 1 dwarf
	2	IIDd	Breeds true
	4	IiDd	13 normal : 3 dwarf
	1	IIdd	Breeds true
	2	Iidd	Breeds true
	1	iidd	Breeds true
Dwarf 3	1	iiDD	Breeds true
	2	iiDd	3 dwarfs : 1 normal

Proportion of each type breeding true and segregating in F_3

Normals { 7 breed true
6 segregate

Dwarfs { 1 breeds true
2 segregate

Three-Factor-Hypothesis

A and D=complementary dwarf factors
I =inhibitor

P_1	Parents.....	IIAADD	x iiaadd	Both normal
F_1		IiAaDd		Normal

F_2 Phenotype and Frequency	Genotype Frequency	Genotype	Behavior in F_3
Normal 55	1	IIAADD	Breeds true
	2	IiAADD	3 normal, 1 dwarf
	2	IIAaDD	Breeds true
	2	IIAADd	Breeds true
	4	IIAaDd	Breeds true
	4	IiAADd	13 normal : 3 dwarf
	4	IiAaDD	13 normal : 3 dwarf
	8	IiAaDd	55 normal : 9 dwarf
	1	IIAAdd	Breeds true
	2	IiAAdd	Breeds true
	2	IIAadd	Breeds true
	4	IiAadd	Breeds true
	1	IIaaDD	Breeds true
	2	IiaaDD	Breeds true
	2	IIaaDd	Breeds true
	4	IiaaDd	Breeds true
	1	IIaadd	Breeds true
	2	Iiaadd	Breeds true
	1	iiaaDD	Breeds true
	2	iiaaDd	Breeds true
	1	iiaadd	Breeds true
Dwarf 9	1	iiAADD	Breeds true
	2	iiAaDD	1 normal : 3 dwarf
	2	iiAAdD	1 normal : 3 dwarf
	4	iiAaDd	7 normal : 9 dwarf

Proportions of each type breeding true and segregating in F_3

Normals	37	breed true
	18	segregate
Dwarfs	1	breeds true
	8	segregate

Of the 85 F_3 families, each the progeny of normal F_2 plants, 38 bred true and 47 segregated. In Table III the results obtained are compared with the theoretical expectation on a two-factor basis.

TABLE III

PROPORTIONS OF TRUE BREEDING AND SEGREGATING FAMILIES IN F_3

	Actual	Theoretical (7:6)	Dev.	P.E.	Dev. / P.E.
Breeding true	38	45.8	7.80	3.10	2.5
Segregating	47	39.2			
			Odds=9.89:1		

The fit is not altogether satisfactory, but it is better than to the 37:18 ratio, the ratio expected according to the three-factor hypothesis. The fit to the latter is given in Table IV.

TABLE IV

DATA FROM TABLE III FITTED TO A 37:18 RATIO

	Actual	Theoretical (37:18)	Dev.	P.E.	Dev./P.E.
Breeding true	38	57.2	19.2	2.92	6.6
Segregating	47	27.8			
			Odds = very large		

Regarding the deviation from the expected 7:6 ratio, it is of interest to note, as shown in Table VI, that the type of segregation of some of the families was such as to indicate that the parents had been wrongly classified in F_2. They gave more dwarfs than normals and the parents were probably of the intermediate dwarf type which, if classified according to height alone, appear to be normal but are really dwarf types, as indicated by the tufted character of the base of the plants. There are four such families, and on removing them from the segregating families, a better fit to the 7:6 ratio is obtained as shown in Table V.

TABLE V

DATA FROM TABLE III FITTED TO A 7:6 RATIO AFTER THE REMOVAL OF CERTAIN FAMILIES

	Actual	Theoretical (7:6)	Dev.	P.E.	Dev./P.E.
Breeding true	38	43.6	5.6	3.03	1.8
Segregating	43	37.4			
			Odds = 3.45:1		

In order to obtain an indication of the nature of the segregation in the different F_3 families, the results were drawn up as in Table VI. They were first placed in order beginning with the family having the largest proportion of normals to dwarfs and were then divided into two classes, those most closely resembling a 13:3 ratio and those most closely resembling a 3:1 ratio. The division into these classes was made on the basis of statistical goodness of fit. On account of the decided resemblance between the two ratios, this can hardly be strictly accurate. However, it must be approximately so, as chance distribution would result in an almost equal overlapping of the classes.

TABLE VI

SEGREGATION FOR NORMALS AND DWARFS OF F_3 FAMILIES FROM NORMALS IN F_2 GENERATION OF KOTA-MARQUIS CROSS

Family No.	Normal	Dwarf	Dev. Calc. (13:3)	P.E.	Dev./P.E.
527	29	1	4.62	1.44	3.2
454	15	1	2.00	1.05	1.9
480	56	4	7.25	2.04	3.6
483	20	2	2.13	1.23	1.7
470	33	4	2.94	1.60	1.8
488	54	7	4.44	2.06	2.2
468	14	2	1.00	1.05	1.0
512	49	7	3.50	1.97	1.8
457	40	6	2.62	1.79	1.5
449	39	6	2.44	1.77	1.4
456	45	7	2.75	1.90	1.4
509	32	5	1.94	1.60	1.2
529	50	8	2.88	2.00	1.4
477	29	5	1.38	1.54	0.9
446	31	6	0.94	1.60	0.6
517	45	9	1.13	1.93	0.6
493	34	7	0.69	1.69	0.4
524	28	6	0.38	1.54	0.2
513	27	6	0.19	1.51	0.1
442	39	9	0.00	1.82	0.0
492	46	11	0.31	1.99	0.2
476	32	8	0.50	1.66	0.3
496	12	3	0.18	1.02	0.2
521	28	7	0.43	1.56	0.3
450	27	7	0.62	1.54	0.4
458	23	6	0.56	1.42	0.4
523	30	8	0.87	1.62	0.5
455	41	11	1.25	1.90	0.7
			Dev. Calc. (3:1)		
530	31	9	1.00	1.85	0.5
522	34	10	1.00	1.94	0.5
464	10	3	0.25	1.05	0.2
482	20	6	0.50	1.49	0.3
511	36	11	0.75	2.00	0.4
491	25	8	0.25	1.68	0.1
447	27	9	0.00	1.75	0.0
520	27	9	0.00	1.75	0.0
443	50	17	0.25	2.39	0.1
475	21	8	0.75	1.57	0.5
526	38	15	1.75	2.13	0.8
490	12	5	0.75	1.20	0.6
506	36	18	4.50	2.15	2.1
514	28	14	3.50	1.89	1.9
478	19	10	2.75	1.57	1.8
479	11	14	1.75	1.46	5.3
481	7	10	5.75	1.20	4.8
474	10	17	10.25	1.52	6.7
486	10	24	15.50	1.70	9.1

This method of dividing the families places 28 families in the 13:3 class and 15 in the 3:1 class. This gives a very close fit to the expected 2:1 ratio as shown in Table VII.

TABLE VII

NUMBERS OF F_3 FAMILIES FALLING INTO 13:3 AND 3:1 CLASSES, AND CALCULATION OF FIT TO A 2:1 RATIO

	Actual	Theoretical (2:1)	Dev.	P.E.	Dev. / P.E.
13:3 class	28	28.7	0.7	2.09	0.3
3:1 class	15	14.3			
			Odds=very low		

With the exception of the last four families, the ratios are surprisingly uniform, especially when the small number of individuals in most of the families is taken into consideration. The goodness of fit was studied further by determining the number of families in each class that fall within the limits of 1, 2, 3, and 4 times the probable error. The results of such a determination are given in Table VIII. The actual results are well within expectation.

TABLE VIII

NUMBER OF FAMILIES FALLING WITHIN THE LIMITS OF 1, 2, 3, AND 4 TIMES THE PROBABLE ERROR AND COMPARISON WITH THE THEORETICAL

Within limits of	No. of families	Per cent of families	Theoretical per cent
CLASS 13:3			
1 x P.E.	16	57	50.0
2 x P.E.	25	89	82.3
3 x P.E.	26	93	95.7
4 x P.E.	28	100	99.3
CLASS 3:1			
1 x P.E.	12	80	50.0
2 x P.E.	14	93	82.3
3 x P.E.	15	100	95.7
4 x P.E.	15	100	99.3

From the 121 dwarfs obtained in F_2, 24 plants were selected at random and their progeny grown in F_3.

The results of the segregating families are given in Table IX. There are 18 such families out of the 24, making the ratio of segregating to true breeding types 18:6. As shown in Table X, this gives a good fit to the theoretical 2:1 ratio according to the two-factor hypothesis.

TABLE IX

SEGREGATION OF F_3 FAMILIES FROM DWARFS IN F_2

Family No.	Normal	Dwarf	Dev. Calc. (1:3)	P.E.	Dev./P.E.
498	2	11	1.25	1.05	1.2
499	2	36	7.50	1.80	4.2
500	1	5	0.50	0.72	0.7
502	5	9	1.50	1.09	1.4
534	1	11	2.00	1.01	2.0
557	1	11	2.00	1.01	2.0
558	5	10	1.25	1.13	1.1
561	1	8	1.25	0.88	1.4
562	11	7	6.50	1.24	5.2
563	2	13	1.75	1.13	1.5
564	4	8	1.00	1.01	1.0
565	7	12	2.25	1.27	1.8
566	1	12	2.25	1.05	2.1
567	8	9	3.75	1.20	3.1
568	2	15	2.25	1.20	1.9
570	2	8	0.50	0.92	0.5
571	2	14	2.00	1.17	1.7
572	3	5	1.00	0.83	1.2

TABLE X

FREQUENCIES OF TRUE BREEDING AND SEGREGATING FAMILIES IN F_3 FROM DWARFS IN F_2

	Actual	Theoretical (2:1)	Dev.	P.E.	Dev./P.E.
Segregating	18	16	2.0	1.56	1.3
Breeding true	6	8			
			Odds=1.63:1		

Dwarf plants as a rule are partially sterile and therefore do not produce many seeds per plant. The F_3 families were consequently rather small, much too small, in fact, to expect a reasonable agreement within each family to the theoretical 3:1 ratio. Furthermore, the deviations are on the whole so large that the required number of families do not fall within the limits set by 1, 2, 3, and 4 times the probable error. This is illustrated in Table XI.

TABLE XI

NUMBER OF FAMILIES FALLING WITHIN THE LIMITS OF 1, 2, 3, 4, 5, AND 6 TIMES THE PROBABLE ERROR AND COMPARISON WITH THE THEORETICAL

Within limits of	No. of families	Per cent of families	Theoretical per cent of families
1 x P.E.	3	16.7	50.0
2 x P.E.	14	77.8	82.3
3 x P.E.	15	83.3	95.7
4 x P.E.	16	88.9	99.3
5 x P.E.	17	94.4	99.9
6 x P.E.	18	100.0	100.0

One family (No. 562) deviates so widely from the expected 3:1 that there is some possibility that the plant from which it came was wrongly classified in F_2. When this family is removed, the agreement is as in Table XII.

TABLE XII

SAME AS TABLE XI WITH FAMILY NO. 562 REMOVED

Within limits of	No. of families	Per cent of families	Theoretical per cent of families
1 x P.E.	3	17.6	50.0
2 x P.E.	14	82.4	82.3
3 x P.E.	15	88.2	95.7
4 x P.E.	16	94.1	99.3
5 x P.E.	17	100.0	99.9

The agreement is still poor for the class 1 × P.E. That this is probably due to the small number of individuals in most of the families is shown by the relation of the average deviation from the 3:1 ratio to the average probable error. The latter was determined by the formula:

$$\frac{1}{N}\sqrt{m_1^2\,a^2+m_2^2\,b^2+\text{----}+m_n^2\,y^2}$$

where m_1, m_2, ---- m_n are the numbers of individuals in each family; a, b, c, --- y, are the probable errors of a 3:1 ratio for each family, and $N=m_1+m_2+\text{---------}+m_n$. (Roberts, 16). The calculations are given in Table XIII.

TABLE XIII

SEGREGATION OF F_2 FAMILIES FROM DWARFS IN F_2 AND RELATION OF AVERAGE DEVIATION TO THE AVERAGE PROBABLE ERROR

	Actual average	Theoretical average (3:1)	Average dev.	Average P.E.	Dev./P.E.
			Odds=about 1:1		
Dwarf	11.333	10.999	0.334	0.355	about 1.0
Normal	3.333	3.667			

The fit is good and indicates that the general tendency when all of the families are considered is decidedly toward a 3:1 ratio.

Backcrosses of dwarfs with parents.—During the summer of 1924 crosses were made between dwarfs from true breeding lines and both parents of the original cross. In all cases the dwarfs were used as the female parent as it was almost impossible to obtain an appreciable amount of pollen from the dwarf anthers. Several grains of each of the crosses were obtained and were grown in the greenhouse during the winter of 1924-25. Backcrosses with the Kota parent gave F_1 plants which were all normal while backcrosses with the Marquis gave all dwarf or intermediate dwarf plants in F_1. Those results can best be appreciated by reference to Figure 1, which is a photograph of a typical pot of plants from each cross. The breeding behavior in the backcrosses is in agreement with the two-factor hypothesis.

	Kota		Dwarf
Parents	IIDD	×	iidd
	IiDd		
F_1	Normal		
	Marquis		Dwarf
Parents	iidd	×	iiDD
	iiDd		
F_1	Dwarf		

Most of the dwarfs obtained from the backcross with Marquis were quite typical, but a few of them were obviously of the intermediate type. These intermediate plants are apparently individuals heterozygous for the dwarf factor which, when heterozygous, often does not exhibit complete dominance.

DWARFING IN A CHUL-MARQUIS CROSS

Breeding behavior in F_1 and F_2 generations.—In the F_1 generation of this cross all the plants were normal. In the F_2 a ratio of 206 normals to 60 dwarfs was obtained. As shown in Table XIV, this may be regarded as a 3:1 or a 13:3 ratio, altho the fit is better for the former.

TABLE XIV

SEGREGATION IN F_2 OF CHUL-MARQUIS CROSS FOR NORMALS AND DWARFS AND CALCULATION OF GOODNESS OF FIT TO 3:1 AND 13:3 RATIOS

	Actual	Theoretical (3:1)	Dev.	P.E.	Dev./P.E.
Normal	206	199.5	6.5	4.76	1.4
Dwarf	60	66.5			
			Odds=1.90:1		

	Actual	Theoretical (13:3)	Dev.	P.E.	Dev./P.E.
Normal	206	216.1	10.1	4.29	2.4
Dwarf	60	49.9			
			Odds=8.48:1		

Breeding behavior in F_3 generation.—The progeny of 24 normal plants in F_2 were grown in F_3. Of these, 15 families bred true and 9 segregated. This result is compared in Table XV with the theoretical proportions (7:6) for the two-factor hypothesis, and 37:18 for the three-factor hypothesis.

TABLE XV

FREQUENCIES OF TRUE BREEDING AND SEGREGATING FAMILIES IN F_3 AND COMPARISON WITH THE THEORETICAL 7:6 AND 37:18 RATIOS

	Actual	Theoretical (7:6)	Dev.	P.E.	Dev. / P.E.
Breeding true	15	12.9	2.1	1.65	1.3
Segregating	9	11.1			
			Odds = 1.63:1		

	Actual	Theoretical (37:18)	Dev.	P.E.	Dev. / P.E.
Breeding true	15	16.1	1.1	1.55	0.7
Segregating	9	7.9			
			Odds = very low		



Fig. 1. F_1 of the Backcrosses as Grown in the Greenhouse, 1924-25

In both cases true-breeding dwarf lines were backcrossed with both parents. The plants in the two pots in the center are perfectly normal while those in the outside pots are typical dwarf. Marquis U is the line used in the Kota-Marquis cross and Marquis T in the Chul-Marquis cross.

In Table XVI are given the actual results for each of the F_3 families. These have been divided according to statistical goodness of fit into the ratio groups 13:3 and 3:1. The probable errors are given and their relation to the deviations from the theoretical ratio which the type of segregation most nearly fits.

When the families are divided in this manner, 8 of them fall into the 13:3 class and only 1 into the 3:1 class. However, the number of families is too small to expect much similarity to the theoretical 2:1 ratio. The number is also too small to expect at least 50 per cent of them to deviate from the theoretical not less than 1 times the probable error. The significant feature of these results is that some of the

families possessing a fair number of individuals vary widely from the theoretical ratios. In the case of families 433 and 422, the odds are very large that these are something other than 13:3 ratios. They are much closer to a 63:1 ratio.

TABLE XVI

SEGREGATION OF F_3 FAMILIES FROM NORMALS IN F_2

Family No.	Normal	Dwarf	Dev. Calc. (13.3)	P.E.	Dev./P.E.
433	67	1	11.75	2.17	5.4
422	67	3	10.13	2.20	4.6
420	49	5	5.13	1.93	2.7
419	53	8	3.44	2.06	1.7
417	36	5	2.69	1.69	1.6
421	23	4	1.07	1.37	0.8
427	81	15	3.00	2.58	1.2
432	57	11	1.75	2.17	0.8
			Dev. Calc. 3:1		
414	73	24	0.25	2.88	0.1

Backcrosses of dwarfs with parents.—Similar backcrosses of true breeding dwarfs with both of the parents were made here as for the Kota-Marquis cross. The results are essentially the same as illustrated in Figure 1. Here the Chul parent carries the dominant factors IIDD and the Marquis parent is again of the constitution iidd. The parental material used for the backcrosses was from the same source as that used in the original cross.

CYTOLOGICAL STUDIES

In view of the fact that in studies of the inheritance of dwarfing in wheat, previous workers had frequently obtained ratios that were not easily explained and that in certain cases the dwarfing character appeared to be associated with variations in the normal chromosome number, it was thought advisable in this investigation to make at least a preliminary cytological examination of the material studied.

Methods.—Chromosome counts were made from both root tip and pollen mother cells. It was found that with some practice fairly reliable counts could be made on root tip cells. It is necessary to make counts in a number of cells and to base the final conclusion on the chromosome number most frequently obtained. In really satisfactory preparations the correct number is practically always found. The sections were cut 10 to 12.5μ thick and counts were made only on cells containing all the chromosomes. Allen's (1) modification of Bouin's killing and fixing solution was used for both root tips and pollen mother cells, and Haidenhain's iron alum haematoxylin was used for staining. In making preparations of pollen mother cells it was found that direct contact of the killing fluid with the anthers is necessary to get good fixation of the dividing cells. If the glumes are allowed to remain on the florets, fixation is rarely satisfactory.

Results.—Chromosome counts in root tip cells of the parents and of both normals and dwarfs in the progeny gave 42 in each case. (Plate I, Figs. 1, 2). In the pollen mother cells of dwarfs from the Kota-Marquis cross, good figures were obtained showing 21 bivalents at the heterotypic metaphase (Plate I, Fig. 3). Most of the figures were regular, as shown in Plate I, Fig. 4, but an occasional cell showed a lagging chromosome (Plate I, Fig. 5). Such irregularities were not more frequent in general than in the parental material, it being fairly easy to find an occasional lagging chromosome in side views of the heterotypic metaphase in Marquis wheat. In the progeny of the Chul-Marquis cross only an occasional plant was found among both normals and dwarfs in which the reduction division figures were uniformly regular. As shown in the accompanying drawings and photographs, the irregularities take the form of lagging chromosomes (Plate I, Figs. 6, 7, 8, 9) which are most frequently and most easily observed in side views of the heterotypic metaphase. There is usually only one lagging chromosome present, altho in one case two were quite clearly observed. No attempt was made to count the chromosomes of these plants in polar views of the heterotypic metaphase, as it was evident that either 21 or 20 would be obtained, depending on the presence or absence of a lagging chromosome. The counts in somatic cells, however, were considered to be sufficient proof that the complete number (42) was present. The fate of the lagging chromosomes was not worked out in detail, but it was evident in some cases that they divided in the heterotype and that the halves passed to opposite poles. Occasionally, as shown in Plate I, Fig. 8, a lagging chromosome is caught in the mid-body and disintegrates, and in other cases (Fig. 9) vacuolation seems to be taking place in the lagging chromosome at the time of the heterotypic metaphase. The fate of such a chromosome is doubtful.

INTERPRETATION OF CHROMOSOME BEHAVIOR

The frequent irregularities observed in the reduction divisions of the pollen mother cells of the Chul-Marquis progeny suggested a possible explanation for some of the F_3 ratios which deviated widely from the calculated on a two-factor basis. It will have been noted that altho the number of families grown was rather small, the variation from the expected is in some cases statistically significant. In the Kota-Marquis data it is evident that the results are sufficiently regular to justify their explanation on a two-factor basis, and correlated with this there is approximate regularity in the process of reduction division. The type of irregularity described furnishes a general explanation for widely deviating ratios on the same basis as that advanced by Winge

(30). He finds what appears to be a similar phenomenon in the reduction division figures of Speltoid-Heterozygotes and one or two other mutant types, and points out that this provides a reasonable explanation for the aberrant ratios obtained in studies of the inheritance of these types by Nillson-Ehle, Akerman, Linhard, and Kajanus.[3]

According to Winge's conception of diploid, tetraploid, and hexaploid species such as exist in wheat, the chromosomes may be considered to be in sets which consist of somewhat similar pairs of homologous chromosomes. Taking seven pairs as the chromosome complement of the primitive ancestor of the tetraploid and hexaploid species, when a tetraploid species arises by reduplication of all the chromosomes of the diploid species it then possesses instead of 7 pairs, 7 sets of four. In each set, if the chromosomes all unite at diakinesis, they may be spoken of as tetrasomes (Blakeslee, 3), but in normal varieties of *Triticum durum* or *dicoccum* this does not take place, so it is simply considered as a four-chromosome set. In hexaploid species there will be 7 of such sets of 6 chromosomes each. It should be pointed out here in order to be absolutely clear that when referring to chromosome sets in this sense there is no reference to the haploid groups which probably consist of entirely distinct chromosomes. This conception agrees with that of Blakeslee (3), who would evidently consider 28-chromosome wheats as double diploids and 42-chromosome wheats as tri-diploids, since the chromosomes always unite in pairs and not as tetrasomes or hexasomes.

The chromosome relationships in the wheat species groups may be represented, therefore, as in Diagram 1.

Diagram 1. Representation of the Theoretical Chromosome Relationships in the Wheat Species Groups

Einkorn $\frac{1\ 2\ 3\ 4\ 5\ 6\ 7}{1\ 2\ 3\ 4\ 5\ 6\ 7} = 14$

Emmer $\frac{A^1\ B^1 + A^2\ B^2 + A^3\ B^3 + \ldots\ldots + A^7\ B^7}{A^1\ B^1\ \ A^2\ B^2\ \ A^3\ B^3\ \ A^7\ B^7} = 28$

Spelt $\frac{A^1B^1C^1 + A^2B^2C^2 + A^3B^3C^3 + \ldots\ldots + A^7B^7C^7}{A^1B^1C^1\ \ A^2B^2C^2\ \ A^3B^3C^3\ \ A^7B^7C^7} = 42$

[3] For literature citations see Winge (30).

This diagram is easily understood when it is observed that in the Emmer group $\frac{A^1\ B^1}{A^1\ B^1}$ is supposed to have arisen by duplication of the pair $\frac{I}{I}$ of Einkorn. In reduction division of a hexaploid species, in any one of the groups $\frac{A\ B\ C}{A\ B\ C}$ the normal method of pairing is A with A, B with B, and C with C, but since these pairs are probably more or less homologous, there may in some cases be sufficient affinity between chromosomes that are not strictly homologous to bring about different types of pairing. Normal and certain types of abnormal pairing together with the two kinds of gametes produced are given here.

Normal and abnormal types of chromosome pairing

Normal type (gametes produced)

$$\underline{AA}\ \underline{BB}\ \underline{CC} \text{ or } \frac{ABC}{ABC} \longrightarrow \underline{ABC}$$

Abnormal types

$$\underline{AA}\ \underline{BC}\ \underline{CB} \text{ or } \frac{ABC}{ACB} \longrightarrow \underline{ABC} + \underline{ABB} + \underline{ACC}$$

$$\underline{AB}\ \underline{AB}\ \underline{CC} \text{ or } \frac{ABC}{BAC} \longrightarrow \underline{ABC} + \underline{BBC} + \underline{AAC}$$

It is evident that such behavior would be liable to introduce irregularities in the usual ratios obtained from factors located in the chromosomes A, B, or C. This is the basis for Winge's explanation of the irregular ratios obtained by the workers previously mentioned.

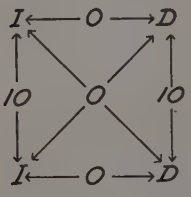
Winge made a further observation, namely, that the production of abnormal gametes furnishes a reasonable explanation for the occurrence of forms in which lagging chromosomes are frequently observed in the reduction division figures. When gametes such as ABC and ABB, or ACC and ACB go to form a zygote, three homologous chromosomes are present. It is reasonable to suppose that in most cases these will form a trivalent and that the remaining chromosome will lag behind.

APPLICATION OF CHROMOSOME BEHAVIOR TO BREEDING BEHAVIOR OF PROGENY OF KOTA-MARQUIS AND CHUL-MARQUIS CROSSES

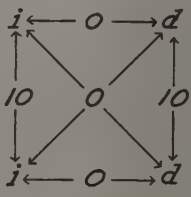
In both crosses the genetic data are sufficient to show that the dwarfing character may be placed on a definite factor basis. However, in the Chul-Marquis material the inheritance data are not as regular as might be expected and as lagging chromosomes were frequently observed in the dwarf and normal material, it appears worth while to attempt a speculation as to how the cytological irregularities might affect the ratios obtained.

In the F_1 of the cross the chromosome of one of the seven groups may be represented as $\frac{A\ I\ D}{A\ i\ d}$. The $\frac{I}{i}$ chromosome pair here carries the inhibiting factor and its allelomorph, and the $\frac{D}{d}$ chromosome pair the dominant dwarf factor and its allelomorph. The $\frac{A}{A}$ pair need not be regarded as carrying any factors that are of immediate concern. In the Marquis parent the chromosome group would be $\frac{A\ i\ d}{A\ i\ d}$ and in the Chul parent $\frac{A\ I\ D}{A\ I\ D}$. In these, chromosome pairing is normal, therefore complete affinity between homologous chromosomes can be assumed and a complete lack of affinity between members of dissimilar pairs. This may be represented as follows where the figure 10 indicates complete affinity and 0 complete lack of affinity.

Chul



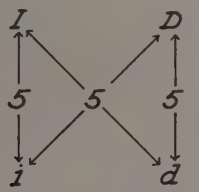
Marquis



In the F_1 of a cross between these varieties it would be expected normally that the $\frac{I}{i}$ pair and the $\frac{D}{d}$ would be completely homologous, but in distantly related varieties it is quite possible that there may be sufficient resemblances and differences among the members of a four-

chromosome set to bring about partial affinity between all members. As a working basis, the assumption is made that the condition is as follows:

F_1 of Chul x Marquis



Here the affinity of I for i is no greater than I for d, and the affinity of D for d is no greater than D for i. This equality is assumed merely for simplicity. It is more logical to assume a somewhat greater affinity of I for i than I for d, but the actual affinity can not be determined, so there is no object in complicating the hypothesis by assuming different values.

This would result in two types of chromosome pairing:

Method of Pairing	*Gametes Formed*
$\frac{I}{i}\ \frac{D}{d}$ ——→	ID, id, Id, iD
$\frac{I}{d}\ \frac{D}{i}$ ——→	ID, id, Ii, Dd

It is impossible to estimate the frequency with which the different types of gametes will be formed, but it appears probable that the abnormal gametes Ii and Dd will be formed somewhat less frequently than the four normal types of gametes, ID, Id, iD, and id.

It should be pointed out here that the abnormal gametes Ii and Di might possibly be formed by non-disjunction in the $\frac{I}{i}$ and the $\frac{D}{d}$ pairs at the same time, the non-disjoining pairs passing to opposite poles. This probably does not take place, as in order to produce the double non-disjunction gametes in appreciable numbers, single non-disjunction would be expected to occur much more frequently. This would result in a large number of gametes containing 20 or 22 chromosomes and these would probably be lethal,[4] or if viable would result in the production of a number of plants possessing 41 or 43 chromosomes. There is no evidence that such plants are produced.

[4] In species crosses, as indicated by Sax (21), there seems to be a distinct tendency at least for the male gametes of this nature to be lethal. It is evident, furthermore, that not to consider these gametes simplifies the hypothesis and is justifiable on the grounds that it does not make a great deal of difference to the theoretical ratios.

When the gametes Ii, Dd, Id, iD, ID, id are produced by the F_1 individuals the genotypes in F_2 will be as shown in Diagram 2.

Diagram 2. Genotypes in F_2 When Abnormal Chromosome Pairing in the F_1 Results in the Formation in Addition to the Normal, of the Abnormal Gametes Ii and Dd

Gametes	Ii	Dd	Id	iD	ID	id
Ii	(1) IiIi	(2) IiDd	(3) IiId	(4) IiiD	(5) IiID	(6) Iiid
Dd	(2) IiDd	(15) DdDd	(7) IdDd	(16) iDDd	(8) IDDd	(17) idDd
Id	(3) IiId	(7) IdDd	(9) IIdd	(2) IiDd	(10) IIDd	(11) Iidd
iD	(4) IiiD	(16) iDDd	(2) IiDd	(18) iDiD	(12) IiDD	(19) iDid
ID	(5) IiID	(8) IDDd	(10) IIDd	(12) IiDD	(13) IIDD	(2) IiDd
id	(6) Iiid	(17) idDd	(11) Iidd	(19) iDid	(2) IiDd	(14) idid

It will be noted in Diagram 2 that the dwarf genotypes are enclosed within heavy lines and that the proportion of normals to dwarfs is 3.5:1. This is of course assuming that all types of gametes are formed with equal frequency, which is very probably not true. If the two types of chromosome pairing $\frac{I\ D}{i\ d}$ and $\frac{I\ D}{d\ i}$ occur with equal frequency the gamete frequencies may be worked out as follows:

Type of Pairing — *Gametes Formed*

(a) $\frac{I\ D}{i\ d}$ ⟶ ID, id, Id, iD

(b) $\frac{I\ D}{d\ i}$ ⟶ ID, id, Ii, Dd

Total=2 ID, 2 id, Id, iD, Ii, Dd

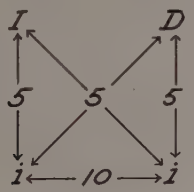
This gametic ratio would represent the maximum production of abnormal gametes, since abnormal pairing occurs as often as normal pairing. The amount of abnormal pairing will make no difference, however, in the F_2 ratio, as the gametes produced by both the (a) and (b) types of pairing will each give a 13:3 ratio of normals to dwarfs.

The effect of abnormal pairing of the chromosomes will therefore be observed only on the F_3 ratios.

On the basis of the relative affinity between chromosome pairs, the expected type of segregation in F_3 for each F_2 genotype may be arrived at approximately. Those which are phenotypically normal and possess dwarf factors will be dealt with.

(2)[5] IiDd or $\frac{A\ I\ D}{A\ i\ d}$ is the same as the F_1 and will give approximately 13 normals to 3 dwarfs.

(4) IiiD or $\frac{A\ I\ D}{A\ i\ i}$ *Chromosome affinities*



It is evident that there are three possible types of chromosome union:

(a) $\frac{i}{i}$ pair and D and I lag, giving the gametes Ii, iD, (IiD), (i), two of which possess one extra or are minus one chromosome and are probably lethal.[6]

(b) $\frac{i}{i}$I form a trivalent and D lags or $\frac{i}{i}$D form a trivalent and I lags, giving the gametes, ID, ii, 2 Ii, 2 iD, (iiD), (I), (2 IiD), (2 i), six of which are probably lethal.

(c) $\frac{I}{i}$ pair and $\frac{D}{i}$ pair and there are no lagging chromosomes. Gives the gametes ID, Ii, id, iD.

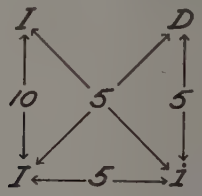
The frequency with which the different types of pairing occur can not be determined, but it is evident that this makes only a slight difference to the final ratios. If (a) alone occurs, the ratio of normals to dwarfs will be 3:1, (b) alone will give a 3.5:1 ratio, and (c) a 4.33:1 ratio.

[5] The numbers, as (2) in this case, refer to the numbers given to each of the genotypes in F_2. See Diagram 2.

[6] See footnote, page 21.

(5) IiID or $\frac{A\ I\ D}{A\ I\ i}$

Chromosome affinities



The possible types of chromosome union are:

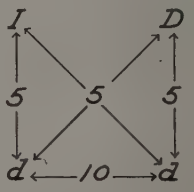
(a) $\frac{I\ D}{I\ i}$ gives the gametes ID, Ii.

(b) $\frac{I}{I}$—i form a trivalent and D lags, gives II, iD, 2 Ii, 2 ID, the other four being lethal.

If only (a) occurs, no dwarfs will be obtained in the progeny while from (b) will be obtained a 35:1 ratio of normals to dwarfs. As there is complete affinity between the $\frac{I}{I}$ pair, (a) would be expected to occur quite frequently so that this type would be expected to give ratios in which there is a considerably greater preponderance of normals than in a 35:1 ratio. The ratios obtained in such families as No. 433, Table XVI, are explainable on this basis.

(7) IdDd or $\frac{A\ I\ D}{A\ d\ d}$

Chromosome affinities



(a) $\frac{d}{d}$ pair, I and D lag, give Id and Dd, the other two being lethal.

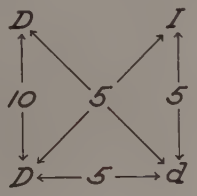
(b) $\frac{d}{d}$—D form a trivalent, I lags, gives ID, dd, 2 Id, 2 Dd, the other six being lethal.

(c) $\frac{d}{d}$—I form a trivalent and D lags, gives ID, dd, 2 Id, 2 Dd, the other six being lethal.

The (a) gametes will give a 3:1 ratio of normals to dwarfs, and the (b) and (c) gametes, which are the same in both cases, a 3.5:1 ratio.

(8) IDDd or $\frac{A\ I\ D}{A\ d\ D}$

Chromosome affinities



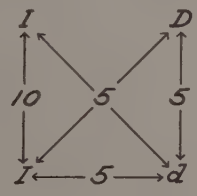
(a) $\frac{D\ I}{D\ d}$ gives ID, Dd

(b) $\frac{D}{D}$—d form a trivalent and I lags, gives Id, DD, 2 DI, 2 Dd, the other four being lethal.

The (a) gametes give a 3:1 ratio of normals to dwarfs and the (b) gametes give the same.

(10) IIDd or $\frac{A\ I\ D}{A\ I\ d}$

Chromosome affinities



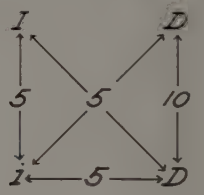
(a) $\frac{I\ D}{I\ d}$ gives ID, Id

(b) $\frac{I}{I}$—d form a trivalent and D lags, gives II, Dd, 2 ID, 2 Id, the other four being lethal.

(a) will give only normals while (b) gives a 35:1 ratio of normals to dwarfs.

(12) IiDD or $\frac{A\ I\ D}{A\ i\ D}$

Chromosome Affinities



(a) $\frac{D\ I}{D\ i}$ gives ID, iD

(b) $\frac{D}{D}$ —i form a trivalent and I lags, gives Ii, DD, ID, iD, the other four being lethal.

Both (a) and (b) give a 3:1 ratio of normals to dwarfs.

The above hypothesis regarding segregation in the F_3 families is summarized in Table XVII.

TABLE XVII

PROBABLE SEGREGATION OF F_3 FAMILIES FROM NORMAL F_2 INDIVIDUALS

No. of F_2 genotype as in Diagram 2	Frequency of occurrence of genotype in F_2	Possible range in expected ratios due to irregular chromosome pairing			
		Normal	Dwarf	Normal	Dwarf
(2)	6	3.5	1	4.33	1
(4)	2	3.0	1	4.33	1
(5)	2	35.0	1	All	0
(7)	2	3.0	1	3.5	1
(8)	2	3.0	1	3.0	1
(10)	2	35.0	1	All	0
(12)	2	3.0	1	3.0	1

DISCUSSION

Our knowledge of the phylogenetic relationships of species and genera has been materially increased during recent years by chromosome study. The first and most evident fact thus revealed is that in related species and genera the chromosome numbers are usually the same or are in multiples of the same number. Thus in wheat and oats we have the haploid numbers 7, 14, 21 (Sakamura, 18; and Sax, 19, 20, 21, 22, 23, 24; and Kihara, 12, 13, 14, 15). A complete review of the polyploid condition in various species and genera has been made by Gates (8).

Studies of the chromosome numbers, however, provide only an indication of the actual relationships. More definite information can be obtained by studies on the compatability of the chromosomes in

different taxonomic groups. Crosses are made and the behavior of the chromosomes in the reduction divisions of the progeny is observed. In crosses of wheat species with different chromosome numbers it has been shown (Sax. 19, 20, 21, 22, 23; and Kihara, 12, 14, 15) that there are indications of a rather close relationship between the species in that chromosome groups in each are homologous and pairing of the chromosomes in these groups is the normal behavior. In some of these crosses there is less affinity than in others with the result that some of the crosses are fertile and some are completely sterile. In wide crosses as between *Triticum vulgare* and *Secale cereale* (Kihara, 12, 15) the affinity between the chromosomes in the formation of bivalents is very weak and as a result the expected number of bivalents, 7, are seldom, if ever, found. In other instances (Collins and Mann, 7) a cross of *Crepis setosa* and *C. capillaris* possessing 3 and 4 chromosomes haploid respectively, gave no progeny that got beyond the seedling stage. In another cross of *Crepis setosa* and *C. blumis* (20 chromosomes) quite vigorous F_1 plants were obtained. Evidently, as concluded by the authors, the degree of success in these crosses depended more upon the compatibility of the chromosome complements of the parents than upon numbers alone.

It is, accordingly, quite conceivable that in any species in which the varieties are normally interfertile there may be some variation in compatibility of the chromosomes. In crosses between some varieties there may be complete affinity between all the chromosome pairs, while in others there may be an entire lack of affinity between one or more pairs. A lack of affinity is hardly to be expected between varieties that are closely related and morphologically similar. It seems more reasonable to expect it in varieties of apparently widely different origin and with clear-cut morphological distinction. Such is the case with the parents of the crosses used in this study. Chul and Kota are somewhat similar in head type and were both introduced from Russia (Clark, Martin, Ball, 6). They are also taxonomically quite distinct from Marquis, which was used as the other parent in crosses with both of these varieties.

The idea of variable affinity between homologous chromosomes in different varieties was indicated by Blakeslee (4) in a discussion of genetic ratios obtained from a Poinsettia, a simple trisomic mutant of Datura. It was pointed out with respect to the factors Pp for purple carried in the trisome, that three different combinations could be built up by utilizing a strain obtained from Washington possessing a chromosome containing the white factor p and a strain from Germany containing a similar chromosome. The genotype Ppp built up with the chromosome containing p from the German strain gave different ratios

from the other two combinations because the chromosomes carrying the factors for white went to opposite poles too frequently. In the trisomes of the various combinations there was evidently a variation in the affinity among the three chromosomes.

In view of the regularity of the results obtained in the present study from the Kota-Marquis cross, it is somewhat surprising that such was not the case in those reported by Waldron and previously reviewed in this paper. A cytological study of this material might be of considerable interest, as the chief reasons why the results do not fit a simple factor hypothesis are that ratios are obtained which deviate significantly from the expected 3:1, 13:3, 55:9, and 9:7. These widely deviating ratios are close to 15:1 or 63:1 ratios and, as shown above, there is some possibility that they may be explained on the basis of irregular chromosome behavior.

AN OAT DWARF

HISTORY AND BREEDING BEHAVIOR

This oat dwarf was first discovered in some material which was being utilized for a study of the inheritance of the false wild character. The study was initiated while the writer was at the University of Saskatchewan. During the winter of 1921-22 a number of grains were selected from bulk grain of a pure line of Banner Sask. 144. These grains appeared to be intermediate with respect to the false wild character in that they possessed a distinct basal scar which was only evident on close examination. These were grown the following year in individual plant rows together with a number of typical false wild and cultivated grains. The intermediate grains gave false wild, intermediate, and cultivated plants in approximately a 1:2:1 ratio. The actual results are given in Table XVIII.

TABLE XVIII

NUMBER AND TYPES OF PLANTS OBTAINED FROM SELECTED FALSE WILD, INTERMEDIATE, AND CULTIVATED SEEDS

Type of seed planted	Number of plants grown	Number of different types of progeny		
		False wild	Intermediate	Cultivated
False wild	121	120	1	0
Intermediate	63	19	28	16
Cultivated	130	0	2	128

The three individuals from false wild and cultivated grains which fell into the intermediate class may have occurred through errors of classification the previous year, since it was found later that the false wild and cultivated types always breed true.

From the intermediate plants 20 were selected at random and their progeny grown the following year. These gave the three types, and the frequency of their occurrence was false wild 114; intermediate 224; and cultivated 94. Of the 114 false wild plants, 20 were dwarfs, these appearing in 4 out of the 20 families. The dwarfs show a good deal of variability in height, but in general are about half the height of normal plants. They lack vigor and are apparently very susceptible to root-rots. The panicles do not usually emerge completely from the sheaths. The spikelets appear normal, but no seeds are formed.

In these families from intermediate plants there appeared to be three types of segregation, altho the numbers were too small to put this on a definite basis. These types are illustrated in Table XIX.

TABLE XIX

TYPES OF SEGREGATION IN FAMILIES FROM INTERMEDIATE PLANTS

Type I Cultivated, intermediate, and false wild types appear in approximately a 1:2:1 ratio. There are no dwarfs.

	F.W.	Int.	Cult.
Normal	91	198	72
Dwarf	0	0	0
Total	91	198	72

Type II The same three types appear and some of the false wild plants are dwarfed.

	F.W.	Int.	Cult.
Normal	3	15	20
Dwarf	2	0	0
Total	5	15	20

Type III All of the false wild plants are dwarfed and the cultivated class is eliminated.

	F.W.	Int.	Cult.
Normal	0	12	0
Dwarf	18	0	0
Total	18	12	0

One family in type III consisted of 7 intermediate plants and 10 false wild dwarfs. When the progeny of the 7 intermediate plants were grown, the results were as given in Table XX.

TABLE XX

RESULTS BY FAMILIES FOR THE SEGREGATION OF SEVEN INTERMEDIATE PLANTS

Family	Class	Height class in inches								Total
		6	11	16	21	26	31	36	41	
I	F.W.	1	..	9	1	..	..	..	..	11
	Int.	..	..	..	1	2	2	4	..	9
	Cult.	..	..	..	..	..	..	..	1	1
II	F.W.	..	..	..	..	..	..	..	..	0
	Int.	..	..	..	..	1	2	4	1	8
	Cult.	..	..	..	..	1	..	4	8	13
III	F.W.	3	3	5	..	..	..	..	..	11
	Int.	1	..	..	2	..	..	..	..	3
	Cult.	..	..	..	..	..	..	..	..	0
IV	F.W.	1	5	4	..	..	..	..	..	10
	Int.	..	1	1	..	..	5	3	..	10
	Cult.	..	..	..	..	..	..	..	..	0
V	F.W.	1	3	..	..	..	..	..	..	4
	Int.	..	..	3	6	2	1	..	..	12
	Cult.	..	..	..	..	..	..	..	..	0
VI	F.W.	1	1	7	2	..	..	..	..	11
	Int.	..	..	..	3	2	2	2	..	9
	Cult.	..	..	..	..	..	..	..	1	1
VII	F.W.	2	4	4	3	..	..	..	..	13
	Int.	..	..	..	..	2	6	2	1	11
	Cult.	..	..	..	..	..	..	..	..	0
All families	F.W.	5	12	28	15	..	..	..	..	60
	Int.	..	1	4	11	18	15	2	..	63
	Cult.	..	..	..	..	1	..	4	10	15
Families I, III, IV, V, VI, VII	F.W.	5	12	28	15	..	..	..	..	60
	Int.	..	1	4	12	10	16	11	1	55
	Cult.	..	..	..	..	..	..	..	2	2

The general tendency seems to be toward the production of false wild dwarfs and intermediate normals in a 1:1 ratio, while the cultivated type is practically eliminated. Of the total of 15 cultivated plants obtained, 13 appeared in Family II which did not produce any dwarfs. Summarizing all of the families except Family II, as in the lower portion of Table XX, there is a total of 60 dwarfs which are also false wild, and 55 intermediate normals. The results for all the families combined are illustrated graphically in Figure 2. The segregation is quite distinct and the means of the two types are widely different. The average height of the dwarfs in inches was 15.417+.382, and that of the other two classes was 30.423+.577. The difference is 15.006+.692, the significance of which is undoubted.

In order to study the possible relation of the false wild character to dwarfing, a cross was made between a pure line of Banner Sask. 144 and a pure strain of false wild that had been isolated from it. The F_1 of this cross possessed grains which were uniformly intermediate in type and the plants were normal in appearance. In the F_2 generation 436 plants were studied, of which 90 were false wild, 234 intermediate, and 106 cultivated. These plants were measured and classified for

height of tallest culm and average height of culm, the results from which are presented in Figures 3 and 4. As will be noted from these figures, there is no correlation in this case between the grain characters and height of plant.

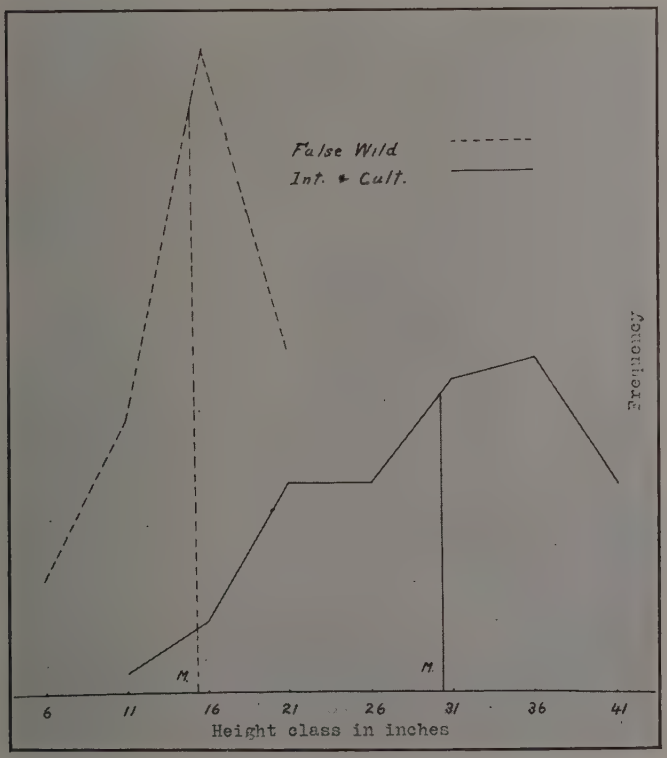


Fig. 2. Graphic Representation of Summarized Data from Table XX

Frequency distribution on a percentage basis for height of tallest culm.

Classes	Mean height in inches
False wild dwarf	15.42 ± .38
Intermediate and cultivated normal	30.42 ± .58

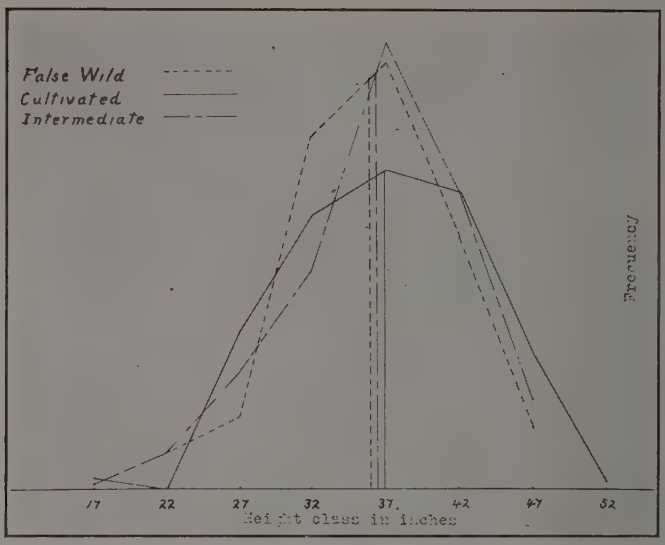


Fig. 3. Frequency Distribution on a Percentage Basis for Height of Tallest Culm for the False Wild, Intermediate, and Cultivated Classes in the F_2 of the Cross Wild x Cultivated

Classes	Mean height in inches
False wild	36.01 ± .377
Intermediate	36.51 ± .279
Cultivated	36.86 ± .425

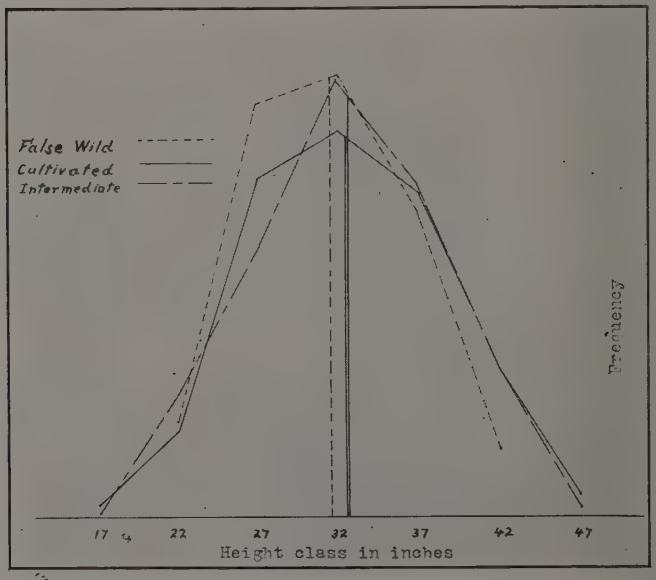


Fig. 4. Frequency Distribution on a Percentage Basis for Average Height of Culm for the False Wild, Intermediate, and Cultivated Classes in the F_2 of a Cross Between False Wild and Cultivated

Classes	Mean height in inches
False wild	31.47 ± .495
Intermediate	32.56 ± .395
Cultivated	32.45 ± .232

CYTOLOGICAL STUDIES

A preliminary cytological study of the dwarfs was made during the summer of 1924. While determining by Belling's method (2) the right stage for fixation in order to obtain division figures in the pollen mother cells, lagging chromosomes were frequently observed and the general appearance of the dividing cells was somewhat different from that of the normal material in that there was a great deal more variation in the stages of division in the same anther. Permanent preparations showed a very surprising degree of irregularity in the reduction division figures. The stages appear to be normal up to and including diakinesis but from then on are very irregular. In the heterotype there is considerable variation in the chromosome behavior. In a few cells, Plate II, Figure 13, behavior is almost normal in that the chromosomes arrange on a fairly distinct equatorial plate and only a few are lagging, but in the majority of cells there seems to be a decided lack of co-ordination among all of the chromosomes. They appear to divide at different times and at various places in the cell, and are therefore to be seen spread about in the cell in different stages of division (Plate II, Figs. 16, 17, 18, 19). No cells were found which were definitely undergoing a homotypic division and it appears probable that this does not take place. The irregular heterotypic division results in the aggregation in different parts of the cell of masses of chromatin which lack the power of undergoing further division. Walls are then laid down separating the masses and a group of irregular and aborted pollen grains results (Plate II, Figs. 21, 23). If the heterotype is fairly regular, only two masses of chromatin are formed and when a wall is laid down between them two giant pollen grains result (Plate II, Fig. 22). Some of these were so large as to indicate that the entire pollen mother cell had developed into a single pollen grain. The large pollen grains and a few others looked normal when fixed and mounted in lactic acid and acid fuchsin, but germination tests were not made. The remainder of the pollen grains, making approximately 95 per cent of the whole, are distinctly abortive.

In connection with these studies, chiefly in order to obtain a general idea as to the nature of normal material, chromosome counts were made on pollen mother cells and root tip cells of *Avena sativa* (normal and false wild), *A. nuda, A. fatua, A. sterilis, A. brevis, A. barbata,* and *A. strigosa.* As shown in Plate I, Figures 10, 11, 12, the last three were found to possess 7 chromosomes haploid. The remaining species gave counts of 21 haploid, and root tip figures gave 42. A count was also made on root tip cells of Stanton's prolific dwarf (25). Good figures were obtained showing 42 chromosomes.

DISCUSSION

At present it seems that not sufficient genetic and cytological data have been obtained to furnish a basis for a reasonably sound explanation for the occurrence and behavior of the oat dwarf. The cytological irregularities indicate that something is lacking which has a profound influence on the co-ordination of the chromosomes during reduction division. This may be either a single factor, a part of a chromosome containing several to many factors, or one or more whole chromosomes. The fact that all the dwarf plants are false wild seems to indicate that at least a part of a chromosome which also carries the cultivated factor has somehow been lost.

The case of this dwarf appears to be very similar to that reported by Burd (5) in Sea Island cotton. The plants obtained were very much reduced in height and size of parts. Normal dehisence of the anthers did not occur and the pollen was abnormal. The rogues were completely self-sterile and they produced only a few seeds by open pollination. In the pollen, tetrad formation was shown to be very abnormal, any number up to 7 cells being formed from a single pollen mother cell. Burd inclines to the view that the rogue originated by mutational loss.

SUMMARY

1. In a Kota-Marquis cross made and studied at University Farm, St. Paul, dwarf plants appeared in the F_2 and in a definite proportion of the F_3 families. The segregation in F_2 was sufficiently close to a 13:3 ratio to indicate that two factors were involved, a dominant dwarf factor D and an inhibitor I. In F_3 the proportion of true breeding and segregating families, the types of segregation in individual families, and the proportions of the different types of segregation gave further proof of the two-factor hypothesis.

2. In a Chul-Marquis cross, made and studied first by Dr. W. P. Thompson at the University of Saskatchewan, sufficient data were obtained from the segregating generations to indicate that two factors of the same nature as in the case of the Kota-Marquis dwarfs govern the inheritance of the dwarf condition. Here the segregation in F_2 is approximately 13 normals to 3 dwarfs. In the F_3 generation, types of segregation occur which do not correspond wtih the simple factor explanation.

3. Backcrosses of true breeding dwarfs to the parents, produced in the F_1 generation only dwarfs in the cross of Dwarf x Marquis, and only normals in the crosses of Dwarf x Kota and Dwarf x Chul. This is considered sufficient proof of the presence of an inhibiting factor in the Kota and Chul parents which prevents the expression of a dwarf factor.

4. A cytological study of the dwarfs obtained from both crosses led to the conclusion that in the Kota-Marquis dwarfs chromosome number and behavior are as normal as in the parental material. In the Chul-Marquis dwarfs, lagging chromosomes were present in most of the cells undergoing reduction division.

5. It was suggested that the lagging chromosomes may have resulted from the presence in the heterotypic division of three homologous chromosomes which formed trivalents and allowed the remaining chromosome to lag behind. Such cells might arise through irregular pairing of the chromosomes in the mother cells of the F_1 plants and the recombination of the aberrant gametes so formed. Irregularities of this type affecting the chromosome pairs carrying the dwarf factor or factors and the inhibitor would result in the occurrence in F_3 of families showing a segregation varying from 3:1 of normals to dwarfs to practically all normals. This would easily account for the obtaining of ratios approximating 63:1.

6. An oat dwarf was found in the progeny of plants heterozygous for the false wild character. These dwarfs are only about one-half the height of normal plants, are completely sterile, and always possess the false wild character. The progeny of normal plants heterozygous for the false wild factor usually consist of a 1:2:1 ratio of false wild, intermediate, and cultivated individuals, but when dwarfs occur in families from such plants the cultivated class is practically eliminated and the remainder consist of false wild dwarfs and intermediate normals in a 1:1 ratio.

7. A cytological study of the pollen mother cells of the oat dwarf showed that reduction division is extremely irregular. There seems to be an almost complete lack of co-ordination among the chromosomes at the heterotype, and the homotype probably does not take place. Very few normal appearing pollen grains are formed.

8. There is evidently in the case of the oat dwarf an intimate correlation between dwarfing, the false wild character, cytological irregularities, and complete sterility.

9. Chromosome counts on *Avena sativa, A. fatua, A. sterilis, A. nuda, A. brevis, A. barbata*, and *A. strigosa* gave 42 for the first four species and 14 for the remainder.

10. In these studies the cytological evidence has thrown considerable light on the inheritance data. This would seem to indicate the value of combining the genetic and cytological modes of attack, especially in those cases in which the results obtained are not easily explained on a direct factor basis.

LITERATURE CITED

1. Allen, C. E. Studies on cell division in the albino rat. Anat. Rec. **10**: 365-584. 1916.
2. Belling, J. Microscopical methods used in examining chromosomes in iron-acetocarmine. Amer. Nat. **57**:92-6. 1923.
3. Blakeslee, A. F. Types of mutation and their possible significance in evolution. Amer. Nat. **55**:254-67. 1921.
4. ————. Variations in datura due to changes in chromosome number. Amer. Nat. **56**:16-31. 1922.
5. Burd, L. H. A preliminary note on a sterile dwarf rogue in Sea Island cotton. Empire Cotton Growing Rev. **1**:46-8. 1924.
6. Clark, J. A., Martin, J. H., and Ball, C. R. Classification of American varieties of wheat. U.S.D.A. Bul. 1074. 1922.
7. Collins, J. L. and Mann, Margaret C. Interspecific hybrids in Crepis. II. A preliminary report on the results of hybridizing *Crepis setosa* Hall. with *C. capillaris* (L). Wallr. and with *C. biennis* L. Genetics **8**: 212-32. 1923.
8. Gates, R. Ruggles. Polyploidy. Brit. Jour. Exp. Zool. **1**:153-80. 1924.
9. Harris, J. A. A simple test of the goodness of fit of Mendelian ratios. Amer. Nat. **46**:471-75. 1912.
10. Hayes, H. K. and Aamodt, O. S. A study of rust resistance in a cross between Marquis and Kota wheats. Jour. Agr. Research **24**:997-1012. 1923.
11. Johannsen, W. Elemente der exacten Erblichkeitslehre. Jena, 1913.
12. Kihara, Hitoshi. Über cytologische Studien bei einigen Getreidearten. Mit. I. Spezies-Bastard des Weizens und Weizenroggen-Bastard. Bot. Mag. **33**:17-38. 1919.
13. ————. Mit. II. Chromosomenzahlen und Verwandtschaftsverhältnisse unter Avena-Arten. Bot. Mag. **33**:95-8. 1919.
14. ————. Mit. III. Über die Schwankungen der Chromosomenzahlen bei den Speziesbastarden der Triticum-Arten. Bot. Mag. **35**:19-44. 1921.
15. ————. Cytologische und genetische Studien bei wichtigen Getreidearten mit besonderer Rücksicht auf das Verhalten der Chromosomen und die Sterilität in den Bastarden. Mem. Coll. Sci. **1**:1-200. 1924.
16. Pearl, Raymond. The probable error of a Mendelian class frequency. Amer. Nat. **54**:144-57. 1917.
17. Roberts, Elmer. Fluctuations in a recessive Mendelian character and selection. Jour. Exp. Zool. **27**:157-92. 1918.
18. Sakamura, T. Kurze Mitteilung über die Chromosomenzahlen und die Verwandtschaftsverhältnisse der Triticum-Arten. Bot. Mag. **32**:151-54. 1918.
19. Sax, Karl. Chromosome relationships in wheat. Science, N.S. **54**:413-15. 1921.
20. ————. Sterility in wheat hybrids. I. Sterility relationships and endosperm development. Genetics **6**:399-416. 1921.
21. ————. Chromosome behavior in partially sterile hybrids. Genetics **7**: 513-52. 1922.
22. ————. Endosperm development and F_2 steriiity. Genetics **7**:553-58. 1922.

23. ————. The relation between chromosome number, morphological characters, and rust resistance in segregates of partially sterile wheat hybrids. Genetics **8**:301-21. 1923.
24. ———— and Sax, Hally Jolivette. Chromosome behavior in a genus cross. Genetics **9**:454-64. 1924.
25. Stanton, T. R. Prolific and other dwarf oats. Jour. Heredity **14**:301-04. 1923.
26. Thompson, W. P. Lethal factors in cereals. Proc. West. Can. Soc. Agron. **3**:53-9. 1922.
27. Waldron, L. R. A study of dwarfness in wheat accompanied by unexpected ratios. Genetics **9**:212-46. 1924.
28. Warburton, C. W. The occurrence of dwarfness in oats. Jour. Am. Soc. Agron. **11**:72-6. 1919.
29. Weldon, W. E. R. Mendel's law of alternative inheritance in peas. Biometrika **1**:228-65. 1902.
30. Winge, von O. Zytologische Untersuchungen über Speltoide und andere mutanten-ähnliche Aberranten beim Weizen. Hereditas. Bd. 5, H. 3, pp. 241-86. 1924.

DESCRIPTION OF PLATE I

Fig. 1. Root-tip cell of Chul-Marquis dwarf showing 42 chromosomes. x 900

Fig. 2. Root-tip cell of Kota-Marquis dwarf showing 42 chromosomes. x 900

Fig. 3. Pollen mother cell of Kota-Marquis dwarf. Polar view of heterotypic metaphase showing 21 bivalent chromosomes. x 900.

Fig. 4. Pollen mother cell of Kota-Marquis dwarf. Side view of heterotypic metaphase. x 900

Fig. 5. Pollen mother cell of Chul-Marquis dwarf. Side view of heterotypic anaphase showing 2 lagging chromosomes. x 900

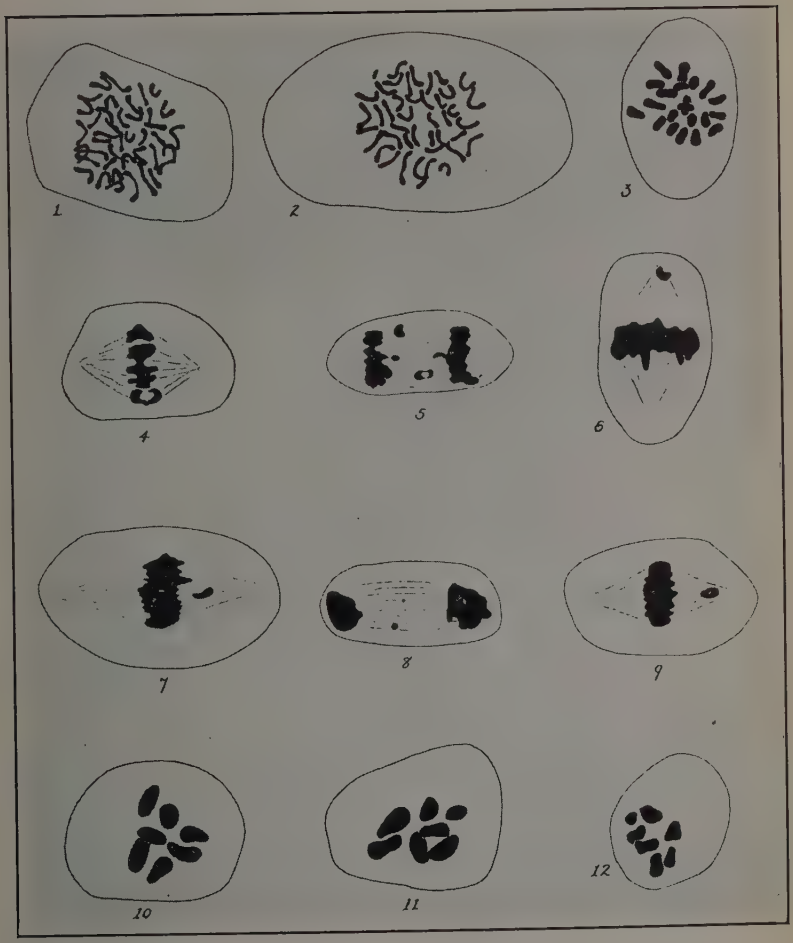
Figs. 6, 7, 9. Pollen mother cells of Chul-Marquis dwarf showing lagging chromosomes in side views of heterotypic metaphase. x 900

Fig. 8. Pollen mother cell of Chul-Marquis dwarf. Side view of heterotypic telaphase showing lagging chromosomes caught in the mid-body. x 900

Fig. 10. Pollen mother cell of *Avena brevis*, drawn from Belling's method preparation, showing 7 bivalent chromosomes in polar view of heterotypic metaphase

Fig. 11. Same as 10 for *Avena barbata*

Fig. 12. Same as 10 for *Avena strigosa*


1
2
3
4
5
6
7
8
9
10
11
12

DESCRIPTION OF PLATE II

Fig. 13. Pollen mother cell of *Avena sativa*, drawn from Belling's method preparation, showing 21 bivalent chromosomes in polar view of heterotypic metaphase

Figs. 14, 15. Pollen mother cells of dwarf oats, drawn from Belling's method preparations, showing lagging chromosomes in side views of heterotypic metaphase

Figs. 16, 17. Pollen mother cells of dwarf oats, side view of heterotypic metaphase showing chromosomes scattered throughout the cells in various stages of division. x 900

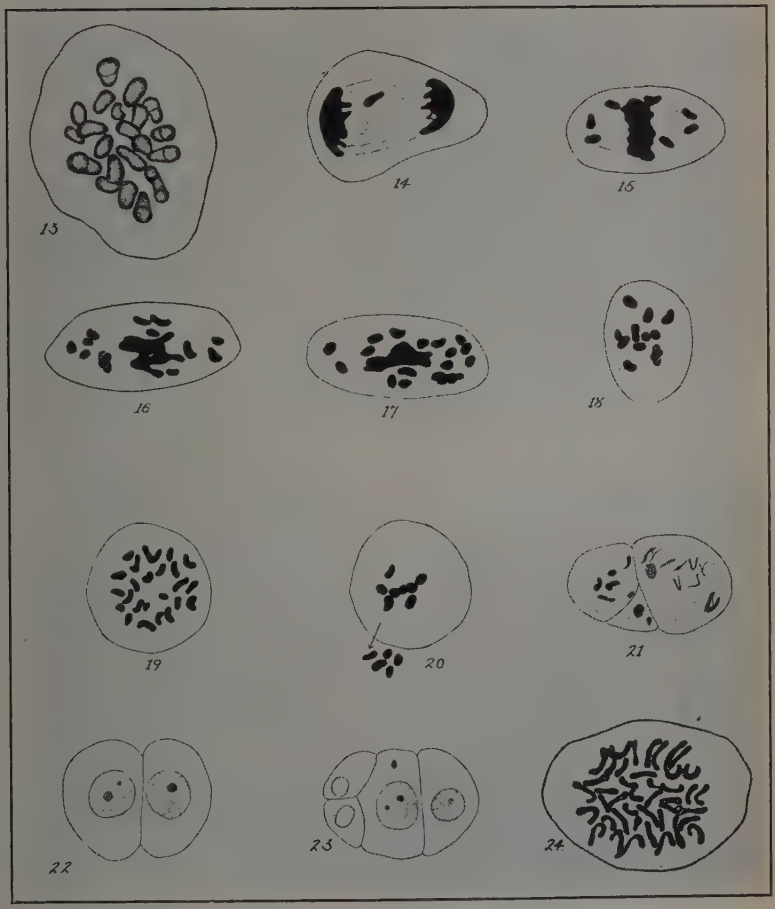
Figs. 18, 19, 20. Polar views of heterotypic metaphase of pollen mother cells of dwarf oats. Show that both univalents and bivalents appear to be present and that all of the chromosomes can not be found in one section. x 900

Fig. 21. Early stage of pollen grain formation in the dwarf oat. Cross walls have been laid down and chromatin masses are disintegrating

Fig. 22. Formation of giant pollen grains in the dwarf oat. The heterotype has been fairly regular and two large nuclei resulted which lacked the power of undergoing a homotypic division. x 900

Fig. 23. A later stage than 21. x 900.

Fig. 24. Root-tip cell of Stanton's prolific dwarf showing 42 chromosomes. x 900


13
14
15
16
17
18
19
20
21
22
23
24

DESCRIPTION OF PLATE III

(Microphotographs)

Fig. 1. Pollen mother cell of Kota-Marquis dwarf plant in which reduction division is regular. Side view of heterotypic telaphase

Fig. 2. Same as Plate I, Fig. 3

Fig. 3. Same as Plate I, Fig. 7

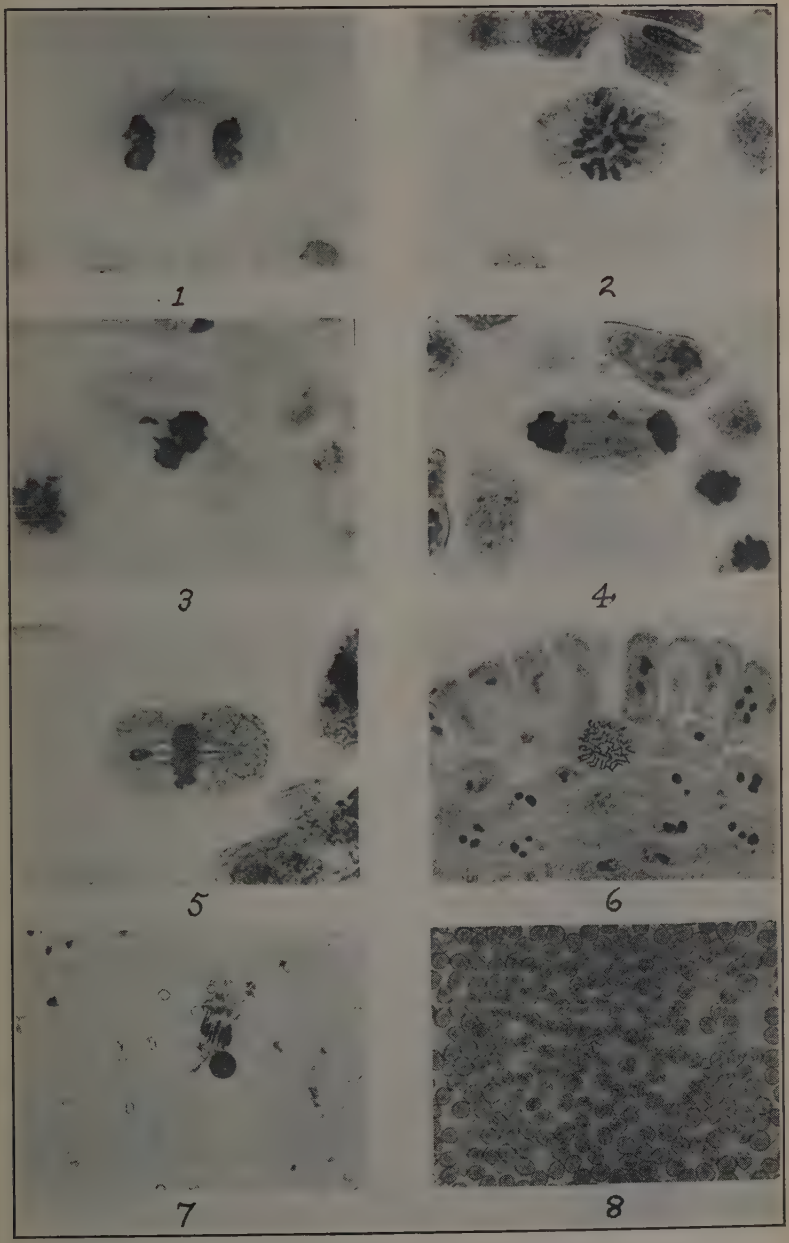
Fig. 4. Same as Plate I, Fig. 8

Fig. 5. Same as Plate I, Fig. 9

Fig. 6. Same as Plate II, Fig. 24

Fig. 7. Pollen from a dwarf oat plant. A single giant pollen grain is shown surrounded by aborted grains of various sizes.

Fig. 8. Normal pollen of *Avena sativa*


1
2
3
4
5
6
7
8

TECHNICAL BULLETIN 34 DECEMBER 1925

University of Minnesota
Agricultural Experiment Station

The Relation of Temperature to Growth and Respiration in the Potato Plant

John Bushnell
Division of Horticulture

UNIVERSITY FARM, ST. PAUL

CONTENTS

		Page
I.	Introductory literature review: The relation of temperature to tuber yields	3
II.	Growth response at controlled temperatures	7
III.	Effect of temperature on respiration with reference to tuber growth	15
IV.	Summary	28
	Literature cited	28

THE RELATION OF TEMPERATURE TO GROWTH AND RESPIRATION IN THE POTATO PLANT

By John Bushnell[1]

I. INTRODUCTORY LITERATURE REVIEW: RELATION OF TEMPERATURE TO TUBER YIELDS

There is convincing evidence that temperature is frequently a limiting factor in yields of the potato *(Solanum tuberosum)*. From an ecological viewpoint, Orton (18) summarized the facts showing that this crop thrives best at relatively cool temperatures. He pointed out: (1) in the Andean region, probably the native habitat of the potato, the mean temperature of the warmest month is only 61° F.; (2) within the United States the highest yields are secured in the regions with the coolest summer temperatures; and (3) of the regions where the crop has been introduced, it perhaps yields best in Scotland and northern Europe, where the mean July temperatures are about 60° F.

Smith (21) analyzed the relation of weather to yields of potatoes in the United States in much greater detail. He showed by maps and isotherms a striking relation between mean July temperatures and average acre yields. Figure 1, which is similar to one of the maps of Smith, shows the ten-year average yields for each state and the isotherms of highest normal temperatures during the growing season. The relation between yield and temperature is obvious. The variations in yield along any given isotherm are largely due to variations in production practices. The yields in the southern states are generally lower than in the northern states traversed by the same isotherms. This is due to the practice of growing the potato in the south as a spring or fall crop, thus avoiding the period of highest temperatures but also shortening the growing period so that the crop is harvested immature and the yields are correspondingly lowered. In this region the isotherms of Figure 1 are shown as broken lines. Along the Atlantic coast the yields are generally higher than in the interior states. A large part of this may be attributed to the influence of the ocean on the temperature as indicated by the trend of the isotherms, but in part this higher yield is due to economic factors. Even without correcting for these variations, there is a conspicuous relation between temperature and yields per acre. This is roughly summarized in Table I.

[1] Formerly of Division of Horticulture.

TABLE I

Approximate Relation of Highest Normal Temperature to Potato Yields as Indicated by Figure 1

Highest normal temperature	Average yields per acre
Deg. F.	Bu.
Below 65	200
65-69	170-100
69-73	120- 80
Above 73	80- 60

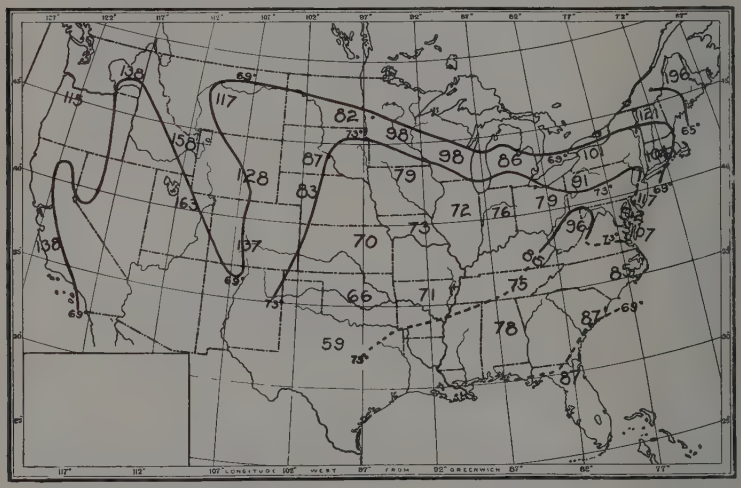


Fig. 1. Average Yields of Potatoes and Isotherms of Highest Normal Temperature During the Growing Period of the Crop (From Data of Smith (21), Bigelow (2), and U. S. Dept. of Agr. Yearbook (25)

Seasonal variations in temperature also have an important bearing on potato yields. Smith (21) attempted to define quantitatively the effect of the different factors of climate by applying statistical treament to records of temperature and rainfall and potato yields in Ohio. He found that temperature gave a more significant correlation with yield than did rainfall, high temperatures being associated with low yields. Furthermore, July temperatures were more important than any others. This led to his suggestion that the crop has a critical period in July when the plant is particularly sensitive to high temperature. The concept of a critical period has not yet been confirmed by other investigations, and it should be pointed out that it is possible to explain the results by another equally plausible hypothesis. The critical period occurred in July, the period of highest temperature in Ohio (see Bigelow, 2). The correlation method used by Smith merely showed that the yield of potatoes was more affected by *departures* from average temperature in July than by corresponding departures in other months.

Thus departures above the normal in July were high enough to be seriously detrimental, while equal departures at other times did not bring the temperature to such a high point and therefore were not so serious. Smith's correlations show that high temperatures depress potato yields, but they do not prove that this is related to a critical period in the growth cycle.

Observations on potato plants grown under greenhouse conditions confirm the climatological evidence that the species is sensitive to differences in temperature. Hardenburg (9) grew crops in two greenhouses, one operating at an average temperature of 15.3° C., the other at 20.3° C. The soil moisture was maintained uniform and equal in the two houses. Larger yields of tubers were produced at the lower temperature.

Fitch (8) grew plants at soil temperatures of 50°, 65°, and 80° F. He published no measurements, but his photographs show the plants growing at 65° to be most vigorous. At the Wisconsin experiment station a larger number of soil temperatures have been available and a more extended series of observations reported. The experiments at Wisconsin have been conducted from the pathologist's viewpoint, but considerable data have been published on uninfected plants. Richards (19) gave measurements on young plants and stated that in a series grown nearly to maturity, soil temperatures of 15° to 18° C. were most favorable. Jones, McKinney, and Fellows (10) gave data in more detail on plants grown to maturity. Table II is from their figures. An interesting feature of these data is the difference in the optimum temperature of the top and the tubers. The largest yield and the largest number of tubers were produced in a soil temperature of 18° C. while the largest weight of green tops was found at 21° C.

TABLE II

INFLUENCE OF SOIL TEMPERATURE ON THE POTATO PLANT. DATA OF JONES ET AL. (10)

Soil temperature, C.	11-12	14.5-15	18	21-21.5	24-25	27-28.5	27-30.5
Av. number of tubers per hill.....	8.2	12.5	11.2	12.5	12.8	14.4	10.2
Av. weight of tubers per hill, gr...	22.0	42.7	56.0	54.2	51.0	25.0	9.5
Av. weight of tubers, gr.	2.6	5.4	7.0	6.0	4.2	2.1	.8
Av. weight of green tops per hill, gr.	55.1	77.0	82.2	89.0	87.0	70.0	50.0
Av. number of stems per hill.....	2.8	3.6	4.2	4.6	4.0	3.2	2.8
Av. height of stems, cm.	22.0	23.0	22.6	23.5	25.0	30.2	14.0
Av. diameter of stems,* cm.	.71	.85	.79	.77	.67	.39	.33
Av. days for plants to come up...	23.0	17.5	12.8	12.8	12.8	16.5	24.6

* Dr. Jones wrote in a letter, September 18, 1925, that the measurements in this line were incorrectly reported and suggested the correction used here.

In summarizing these observations from widely different viewpoints and widely different methods of approach upon different varieties,

there is a rather remarkable agreement on the effects of temperature on this crop. Thus, in regard to the optimum for yield:

Orton's compilation suggests about 16° C.
Smith's surveys indicate 18° or lower
Hardenburg's data give nearer 15° than 20°
Fitch's data suggest about 18°
Jones, McKinney, and Fellows found 18°.

These all point to an optimum for tuber production between 16° and 18° C. Furthermore, these diverse sources agree that yields decline rapidly with increase in temperature above the optimum.

Rôle of moisture.—It is not a simple matter to separate accurately the effect of temperature from that of moisture in studies of the type reviewed here. The writer has found no climatological evidence that moisture, of itself, is an important factor except in arid regions. Potatoes are a commercial crop in the arid west as well as in regions of high rainfall and high humidity. Smith (21) found no really significant correlation of rainfall with yield of potatoes in Ohio. Furthermore, the detrimental effect of high temperature was not definitely associated with rainfall; high temperature depressed yield whether the rainfall was above or below normal. His correlations showed that in Ohio temperature was a more important factor than precipitation.

Humidity has less bearing on the potato crop than rainfall. Excellent yields are obtained under arid conditions, and at the other extreme, excellent yields are produced in humid, maritime climates, particularly in Europe. However, direct experimental evidence bearing on relative humidity, especially at high temperatures, has not been found in the literature. Consequently, a preliminary study bearing on this point was carried out before proceeding with studies on temperature. Potato plants were grown during the summer of 1922 in the chambers later used for the temperature experiments. Three of these chambers were set to operate at 30° C. with relative humidities of 58, 74, and 100 per cent. The results agreed with expectation. In all three chambers the plants produced small leaves and no tubers—typical high temperature responses. No significant differences were observed that could be attributed to differences in humidity.

It is thus evident that temperature of itself, independent of moisture, is an important factor in the yield of potatoes. The following experiments were undertaken, therefore, as a study of the effects of temperature on the plant as a whole, but with particular reference to the physiological mechanisms associated with tuber growth. More specifically, the aim was to find the physiological basis for the decrease in tuber yields at temperatures above the optimum.

II. GROWTH RESPONSE AT CONTROLLED TEMPERATURES

EXPERIMENTAL METHODS

The experiments were carried out in specially constructed, thermoregulated chambers in a greenhouse. Preliminary experiments were run during 1922. The two main plantings were grown in the spring of 1923. The spring months are particularly favorable for greenhouse work, supplying both excellent light and temperatures low enough for studies on a species with a low optimum temperature. The first experimental set of 1923, called series A, was planted in March, series B early in April, and both were discontinued the last week in May.

In order to have a large number of individuals, the plants were grown in eight-inch pots. These appeared to be entirely satisfactory. Tubers of the Early Ohio variety were cut and planted directly in the pots in ordinary sandy soil. The difficulties encountered in securing uniform plants were pointed out in an earlier note (Bushnell, 6). The nts were kept under the same conditions until they were all above

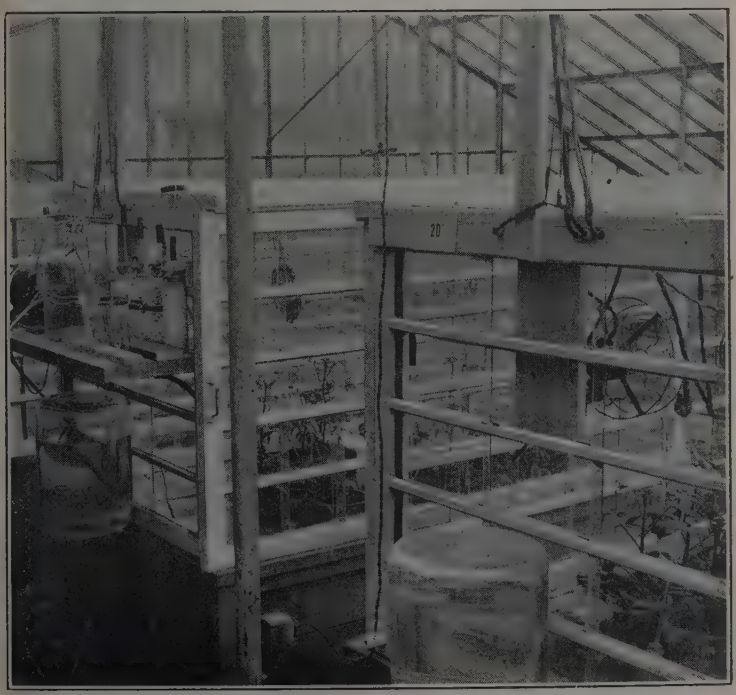


Fig. 2. Theormoregulated Chambers Showing General Features of Construction

ground. Then they were sorted into four equal groups and moved to four chambers operating at 20°, 23°, 26°, and 29° C. In the experimental chambers the plants were watered and measured daily.

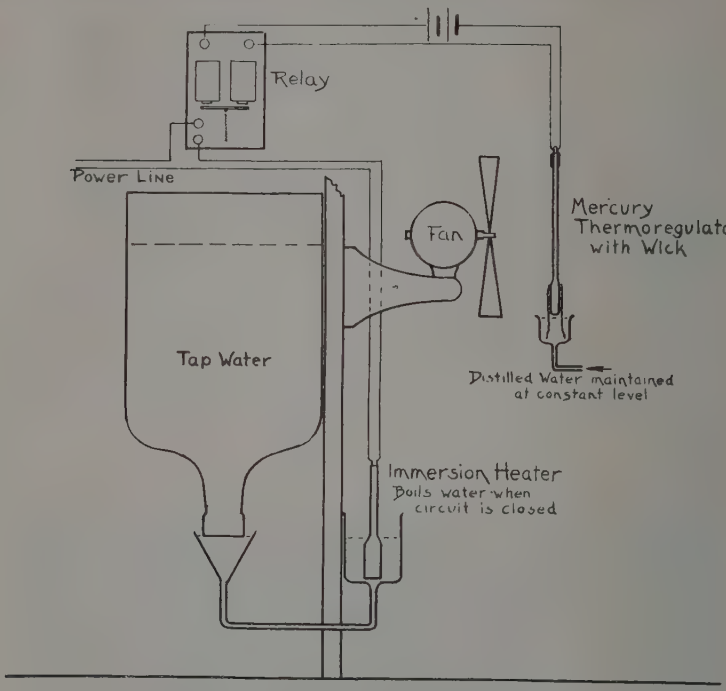


Fig. 3. Diagram of Humidity Regulator

The four chambers were constructed of hotbed sash set on a base 16 inches high. The general features of their construction can be seen from Figure 2. The temperatures were controlled by mercury thermoregulators (Harvey type) operating electric heaters through relays. The heaters were units designed for an electric stove, and being of the resistance wire type did not give any large amount of light. The air was stirred by an electric fan. The humidity control is diagramatically shown in Figure 3. Mercury thermoregulators were adapted to humidity control by covering the bulb with wet linen cloth and placing it in the draft from the fan. By this arrangement they were analogous to wet bulb thermometers. Each was set 5° C. below the air temperature of the chamber, thus maintaining the relative humidity at about 60 per cent in each. As a preliminary experiment had indicated that differences in humidity were not important, this degree of humidity was arbitrarily selected because it was easy to maintain and approximated outdoor humidities.

The temperature range of 20° to 29° was as wide as could be used under the conditions at hand. Refrigeration was not available, so the lowest temperature was determined by the temperature of the greenhouse, and 29° C. was the highest point at which the humidity could be maintained at 60 per cent without excessive condensation of moisture on the glass walls.

The usual difficulties were encountered in controlling the temperature and humidity in chambers of this size. These difficulties have been considered in detail by Tottingham (23). In bright sunlight there was a tendency for the temperature to rise. During April this was satisfactorily controlled by covering the surface of the soil and all dark objects in the chambers with white paper, but during May it was necessary to whitewash an area of the greenhouse roof, partially to shade the chambers during the middle of the day. There was occasional difficulty from the thermostats, chiefly at the relays, due



Fig. 4. Base of Terminal Cluster of Leaves, Which Offers a Relatively Definite Point from Which to Measure the Length of Stem

to overloads. The wicks on the humidity regulators gradually collected dust and had to be renewed every two weeks. Furthermore, it was necessary to add a small amount of mercuric bichloride to the distilled water supplied the wick to prevent growth of micro-organisms. These difficulties, combined with the fact that the chambers were

opened daily in measuring and watering the plants, resulted in actual conditions that were only approximations of the desired temperatures and humidities.

RESULTS

In both series of the main experiments the length of the stem was measured daily on ten plants. The stem was easily measured, as indicated in Figure 4, by taking the distance from the base of the terminal cluster of leaves to the top of the pot. To simplify measurements branches were removed as soon as detected. These measurements are plotted in Figure 5.

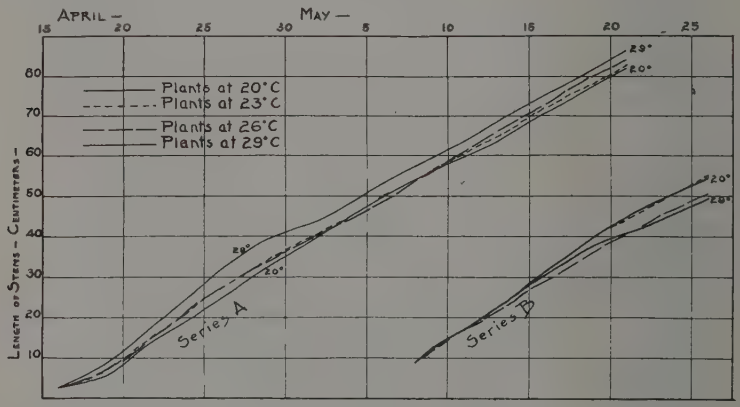


Fig. 5. Growth Curves of Stems

In series A the elongation of the stem during the first ten days of the measurements was more rapid at 29° than at the lower temperatures. This was most conspicuous during the first three days. In series B the plants were not moved to the chambers until they were about ten centimeters tall; thus the two series were not entirely comparable. The final measurements in the two were not in agreement, and as the differences in height were less than five centimeters, the results indicate that temperature had very little effect on the rate of elongation of the stem.

In addition to the plants in the chambers, a set of four plants was grown under the ordinary conditions of the cool greenhouse, parallel with series B except that the branches were not removed. They made a remarkably thrifty growth; evidently conditions were near the optimum for young potato plants. One of these is shown in Figure 6 with a typical plant from each of the temperature chambers. It can be seen in this figure that the height of the plants was not conspicuously affected by temperature. Similarly, under the range of conditions used here the number of nodes was approximately the same. Flower buds

appeared on all plants, abscissing without opening. The one striking effect of temperature was on size of leaflets. This is evident from Figure 6, but is more accurately shown in Figures 7 and 8. The leaflets were not only smaller at the higher temperatures but also lighter green. The differences are illustrated still more accurately by comparing the weight of leaflets with the total weight of the plants (Table III).

No explanation is offered at this point for the effect of high temperatures on the size of leaflets, but the reduction in photosynthetic area undoubtedly plays an important part in the reduced rate of tuber growth.

TABLE III

EFFECT OF TEMPERATURE ON WEIGHT OF LEAFLETS, AND RATIO OF WEIGHT OF LEAFLETS TO TOTAL WEIGHT OF ABOVE-GROUND PART OF THE PLANTS

	Temp. C.	Weight of plant, gm.	Weight of leaflets, gm.	Ratio, per cent
Series A.	May 27. Average of 3 plants from each temperature			
	20°	93	24	25.8
	23°	86	20	23.3
	26°	80	18	22.5
	29°	72	13	18.1
Series B.	May 15 to 20. Average of 7 plants from each temperature			
	20°	44.5	14.4	32.4
	23°	48.9	15.3	31.3
	26°	49.3	15.4	31.2
	29°	41.6	11.4	27.4
Series B.	May 21 to 27. Average of 9 plants from each temperature			
	20°	58.7	18.1	30.3
	23°	65.1	19.8	30.4
	26°	61.3	18.0	29.4
	29°	54.8	14.2	25.9



Fig. 6. Typical Plants from Series B

The plant with the large leaves was grown under ordinary cool greenhouse conditions, the others were from the chambers shown in Figure 3 at the temperatures indicated on the cards (Centigrade).

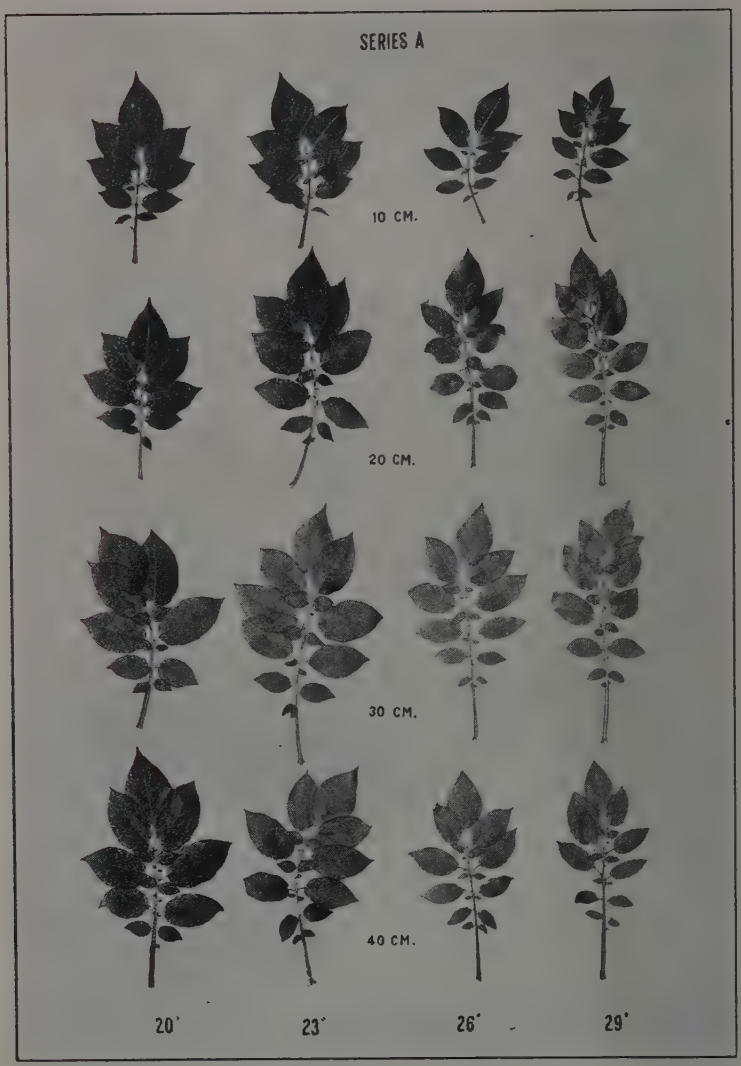


Fig. 7. Effect of Temperature on Size of Leaves at Different Points Along the Main Stem
The measurements indicate the distance from the growing tip of the stem.



Fig. 8. Effect of Temperature on Leaves.

The large leaves were produced in a cool greenhouse, the smaller under incubator conditions at the temperatures given on the labels. Measurements are distances from the tip of the stem.

As pointed out earlier, it was necessary to discontinue the experiment with the advent of high temperatures, the last week in May. At this time the largest tubers on Series B were only about one centimeter in diameter. On Series A, however, the effect of temperature on the tubers showed clearly. (Fig. 9.) At 20° C. all of the plants had tubers two centimeters or more in diameter, while at 29° there was no swelling of the stolons. The average weight of these small tubers is given in Table IV.

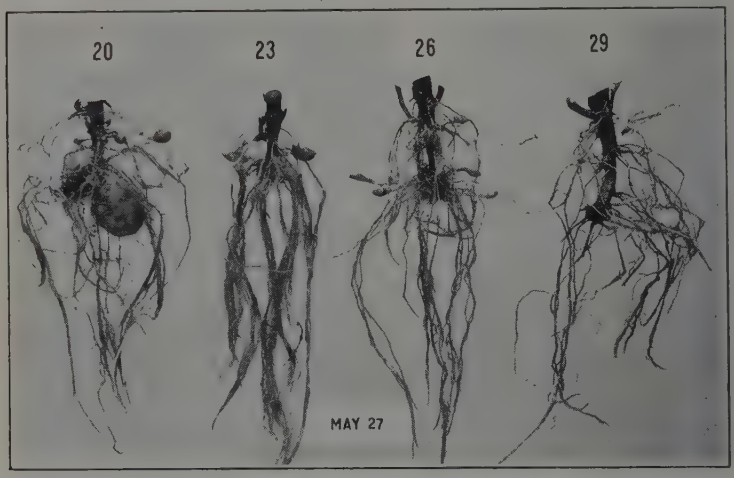


Fig. 9. Effect of Temperature on Early Stages of Tuber Growth

Photographed six weeks after the plants appeared above ground. Grown at the temperatures (C.) indicated by the figures.

TABLE IV

AVERAGE WEIGHT OF TUBERS PER PLANT. SERIES A. MAY 27.

Temperature C.	Weight of tubers Grams
20°	20.9
23°	5.0
26°	1.6
29°	0.0

DISCUSSION

The evidence presented here agrees in all essentials with results reported in the literature. Temperature, by itself, is an important factor in tuber production by the potato plant. An interesting feature of these data is the reduction in size of leaflets at temperatures above the optimum. High temperature at any period after the plants are above ground reduces the size of the leaflets formed at that time, and this reduction in photosynthetic area undoubtedly has an effect on the yield of tubers.

However, the reduction in photosynthetic area was not sufficient to account for the depression in tuber growth at temperatures consistently above the optimum. Under the incubator conditions used here, the difference in tuber growth at any two temperatures was much greater than the difference in size of leaflets. Temperatures above the optimum were more detrimental to tuber development than to growth of other parts of the plant.

III. EFFECT OF TEMPERATURE ON RESPIRATION WITH REFERENCE TO TUBER GROWTH

No studies on the internal physiological reactions of the potato plant to temperature were reported in the literature reviewed in the introduction. Orton (18) suggested that high transpiration might explain the detrimental effect of summer heat, but this is not in accord with the evidence at hand showing that humidity is of relatively minor importance in yields. Since neither humidity nor rainfall has as much bearing on the rate of tuber growth as temperature, and since the effect of temperature is largely independent of moisture, its depressing effect is to be sought in something other than the water relations of the plant. As the tuber is largely *water plus starch*, attention has here been focussed on the production and storage of *starch*. This involves the photosynthesis, respiration, and translocation of carbohydrates by the plant as a whole.

LITERATURE

The literature on the relation of temperature to the physiological processes involved in production and storage of carbohydrates has been reviewed at length by Jost (11) and Kanitz (12) and briefly by Lehenbauer (14). The evidence from this literature leads to the conclusion that photosynthesis is not appreciably affected by the range of temperature under consideration here. The experiments of Matthaei (17), conducted under carefully controlled conditions, showed that in the cherry laurel leaf the rate of photosynthesis increased with increase in temperature over a considerable range when the atmospheric carbon dioxide was artificially increased. Under normal conditions, however, the low concentration of carbon dioxide was a limiting factor. This had been pointed out earlier by Brown and Escombe (4). Thus, with adequate light, increase in temperature accelerated the rate of photosynthesis up to the point where carbon dioxide became the limiting factor. In the case of the potato, however, the *decrease* in rate of starch storage begins at about 17° C. and becomes more and more pronounced the higher the temperature. There is nothing in the classical researches on photosynthesis to indicate that this decrease might be due to a lowering in the rate of carbohydrate synthesis.

On the other hand, the loss of carbon through respiration increases with rise in temperature. Respiration has been studied on various plant organs of a large number of species. In general, it is clearly a function of temperature. Matthaei's data from the work mentioned above are plotted in Figure 10. This curve illustrates the typical relation of temperature to respiration.

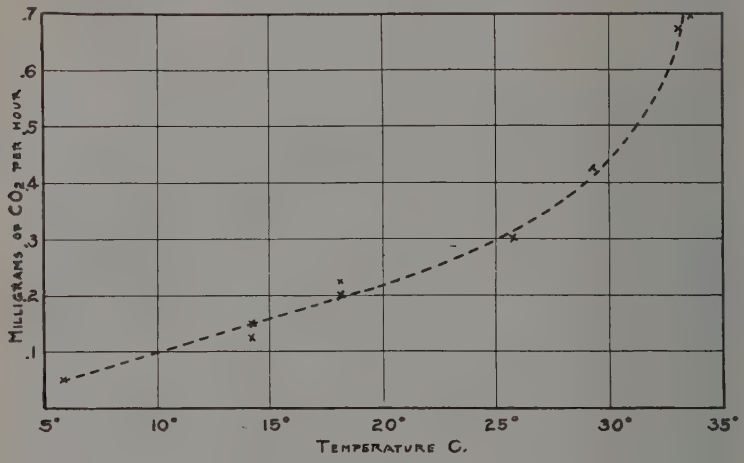


Fig. 10. Effect of Temperature on Rate of Respiration in Leaves of Cherry Laurel (Date of Matthaei 17)

The possibility that the respiration curve might account for the growth curve at temperatures above the optimum was pointed out by Blackman in 1905 (3). Calling attention to the various limiting factors at a growing region of the plant, he wrote:

"To take the hypothetical case that translocation could just bring in, per unit time, enough carbonaceous material for the growth at the optimum temperature *plus* the respiration at the same temperature. Then, as the temperature rose further and the respiration increased *faster and faster*, so necessarily there would be *less and less* carbon material available for growth. The falling curve of growth would become the complement of the rising curve of respiration, and it is of interest that to a large extent, whatever be its significance, the two curves actually have this appearance."

This hypothesis is substantiated by the fact that plants at high temperatures have a low carbohydrate content. Tottingham (23) has reviewed the literature on this point and presented data on buckwheat and clover grown under controlled conditions. Walster (26), also working with plants under controlled conditions, found a lower percentage of soluble carbohydrates and polysaccharides in barley at a temperature near 20° than near 15° C. The generalization is rather

well established: With increase in temperature above the optimum for growth there is a decrease in the soluble and readily hydrolyzable carbohydrates.

The evidence from several angles thus points to deficiency of carbohydrate as a limiting factor at temperatures above the optimum.

In the physiology of the potato plant the importance of this hypothesis is obvious, for the tubers are carbohydrate-storing organs. Any factor increasing the rate of respiration in any part of the plant would correspondingly decrease the carbon available for storage in the tubers. In the present work the problem has been attacked from this viewpoint, particular emphasis being laid on respiration.

ANALYTICAL METHODS

Respiration.—For respiration determinations the plants were disturbed as little as possible. The entire above-ground part of the plant was enclosed in a bell jar, the rim of which was embedded in a layer of paraffin covering the surface of the soil. In thus enclosing a plant it was necessary to remove it from the temperature chamber, apply melted paraffin containing a little rosin to the surface of the soil, cover with the bell jar, and replace it in its chamber. The temperature of the paraffin mixture was about 55° C. when applied, and apparently the stem was not injured by this treatment. The paraffin hardened in about 30 minutes. One plant from each temperature chamber was used for this determination each night from the time the plants were 25 centimeters tall until the close of the experiment, a period of about two weeks.

As soon as the paraffin mixture hardened, each bell jar was connected to a train of three absorption bottles containing strong solutions of sodium hydroxide, and carbon dioxide-free air was drawn through the system for thirty minutes. After this preliminary exhaustion of atmospheric carbon dioxide, an absorption tower, similar to that described by Truog (24), was connected into the system. With this apparatus it was a very simple matter to detect leaks. When the air inlet was closed at one end of the system, the bubbling in the absorption tower ceased if the set-up was air-tight. In a few cases leaks were found by this method, usually around the stem. The determinations on such individual plants were discontinued. As it required more than an hour to prepare a plant, no attempt was made to replace or repair these. In the absorption tower the carbon dioxide given off by the plant was absorbed in 50 milliliters of saturated solution of barium hydroxide. At the close of the determination the residual alkali was titrated with 0.1 normal hydrochloric acid containing one per cent barium chloride. At the close of the respiration period, the bell jar was

removed by melting the paraffin with hot water, and the plant was cut at the surface of the paraffin and weighed. The leaflets were then trimmed off and weighed separately.

Carbohydrates.—In sampling, ten grams of leaflets was rapidly clipped from each of three plants and this composite sample was preserved in hot alcohol containing a small amount of calcium carbonate. The leaflets were taken from the central portion of the plant, thus avoiding the older yellowed leaves and the young actively growing tissue. In a similar manner twenty grams of stems, including petiole, was taken from each plant.

The first steps of the analytical procedure followed the methods of Davis and Sawyer (7). The material was separated into two fractions by extraction with hot alcohol in a modified Soxhlet extractor. An aliquot of the extract was taken for dry matter determination. The balance of the extract containing the soluble sugars was then freed from alcohol by evaporation, taken up in water, clarified with neutral lead acetate, deleaded with disodium phosphate, and made up to volume. An aliquot was treated according to the A.O.A.C. method (1) with hydrodrochloric acid to hydrolyze sucrose.

The insoluble fraction from the extraction was dried, weighed, and part of it hydrolyzed with 1 per cent hydrochloric acid according to the suggestion of Spoehr and McGee (22). They found that in their material 1 per cent hydrochloric acid hydrolyzed the polysaccharide available to the plant for respiration. This method was not entirely satisfactory in potato samples, for the leaves exerted a buffer action that neutralized nearly half of the acid. With the stems this effect was negligible. However, samples from plants grown at different temperatures exerted nearly equal buffer action. The data are retained since there was considerable hydrolysis even at the reduced concentration of acid.

The determinations of reducing sugars were made according to the method of Shaffer and Hartmann (20). Their micro method was used because in some instances the samples were small and the sugar content was low. Klotz (13) reported that in his experience this method was not satisfactory. He stated that for analysis of a synthetic media for fungi the micro method gave "such variable results at different dilutions that it was entirely unsatisfactory for general use." The chief difficulty in the writer's experience arose from rapid titration. Unless the thiosulphate solution was added slowly and with rapid stirring, an excess of the thiosulphate would be added before the end point appeared. This occurred with pure glucose solutions as well as with plant extracts. It was found under the conditions of stirring employed that the thiosulphate solution should not be added at more than

10 milliliters per minute. Where the titration was carried on slowly, the error in the method, even at considerable dilutions, was less than 0.03 milligrams, as indicated in Table V.

TABLE V

EFFECT OF DILUTION ON SUGAR DETERMINATIONS OF POTATO LEAF EXTRACTS
Micro Method of Shaffer and Hartmann

	Sample A		Sample B	
	Found	Calculated	Found	Calculated
	mg.	mg.	mg.	mg.
Original concentration	1.53		1.43	
One-half original concentration	0.74	0.765	0.72	0.715
One-quarter original concentration	0.36	0.383	0.35	0.358

RESULTS

Respiration determinations.—The data on rate of respiration are given in detail in Table VI. These determinations were restricted to series B. Series A was used for a number of preliminary tests but the data were too fragmentary to be included. The sunshine records in this table are from the Minneapolis office of the Weather Bureau, about five miles from University Farm. The green weight of leaves is given because of the great variation in size of plants. In selecting the plants for these determinations, those from the same position in their respective chambers were used rather than those of similar size. The variation in size is partly due to the fact that the ten most uniform plants were being reserved for measurements of growth response, leaving plants both larger and smaller than this modal group for the respiration experiments. From an inspection of the data, however, size of plant seems to have been a negligible factor in the rate of respiration.

TABLE VI

RATE OF RESPIRATION DURING THE NIGHT
Milligrams of CO_2 per 10 Grams of Leaves per Hour

Date	Hours of sunshine noon to sunset	Plants at 20°		Plants at 23°		Plants at 26°		Plants at 29°	
		Weight of leaves	CO_2	Weight of leaves	CO_2	Weight of leaves	CO_2	Weight of leaves	CO_2
May 13	0.4	11.0	3.55	11.0	4.66	11.5	*	8.0	4.85
14	2.5	11.0	3.50	11.5	4.85	11.5	*	8.0	5.98
15	1.5	12.5	3.33	16.0	3.65	17.0	4.05	12.5	3.08
17	5.8	12.5	5.34	19.0	6.27	17.0	6.13	9.0	6.06
18	1.3	18.5	3.71	16.0	5.17	11.5	*	11.5	*
19	0.8	18.5	3.14	16.0	3.58	11.5	*	11.5	4.42
20	6.4	11.5	5.19	10.0	6.17	11.5	6.59	11.0	7.01
21	2.9	5.5	6.07	12.0	6.13	10.0	6.30	5.5	6.88
22	6.0	8.5	4.74	17.0	6.35	16.0	6.41	18.5	6.47
24	4.8	17.0	5.82	18.0	5.92	22.0	6.36	11.5	6.83
25	5.7	21.0	5.12	17.5	5.56	18.0	6.70	15.5	8.71
26	6.4	23.0	6.53	24.0	7.33	15.5	7.52	16.0	9.25
Average: days of 4 hours or more sunshine after noon		...	5.46	...	6.27	...	6.62	...	7.39

* Leak.

When part of these data are summarized graphically as in Figure 11, the daily variations as well as the effect of temperature are illustrated more clearly. The daily variations appear to be in part associated with the age of the plants—the older the plants the higher the rate of respiration at all temperatures. Probably a more important factor is the difference in light intensity from day to day, for it may be noticed that the lower rates are in all instances from data obtained after cloudy days. The one exception was May 21, which is classed as a cloudy day with less than three hours of sunshine in the afternoon, but actually the sun shone brightly for about four hours near noon, and the respiration curve falls in the group following sunny days.

Anticipating that light intensity might play an important rôle, the respiration following the early cloudy days was analyzed in more detail by determining the carbon dioxide respired during the five hours before midnight and during a period of the same length after midnight. Later, comparable figures were secured following bright days. The data are summarized in Table VII.

TABLE VII

EFFECT OF LIGHT INTENSITY DURING THE AFTERNOON ON RATE OF RESPIRATION DURING THE NIGHT

Data are: (1) Milligrams of CO_2 per hour between 7 p.m. and midnight. (2) CO_2 per hour between midnight and 5 a.m. (3) Ratio of respiration before midnight to that after midnight, that is $\frac{(2)}{(1)}$

Temp. of plants:			20° C.			23° C.			26° C.			29° C.		
Date	Sunshine in p.m., hours		(1) 7-12	(2) 12-5	ratio	(1) 7-12	(2) 12-5	ratio	(1) 7-12	(2) 12-5	ratio	(1) 7-12	(2) 12-5	ratio
May 13	Cloudy	0.4	3.59	3.51	0.98	5.72	3.84	0.67	*	...	...	7.20	4.74	0.66
14	"	2.5	3.96	3.08	0.78	*	...	...	*	...	...	9.48	5.35	0.56
15	"	1.5	3.56	3.09	0.87	4.01	3.28	0.82	5.26	2.84	0.54	4.57	1.58	0.35
May 17	Sunny	5.8	5.74	4.89	0.85	6.45	5.91	0.92	6.08	6.18	1.02	6.56	5.45	0.83
20	"	6.4	5.91	4.47	0.76	6.49	5.84	0.90	6.71	6.46	0.96	5.01	9.01	1.80

* Leak.

After the cloudy days more carbon dioxide was respired in the five hours before midnight than in the five hours after midnight. Furthermore, the temperature effect was more conspicuous during the first five hours; the plants at the higher temperatures respired at a higher rate during the first five hours, and the greater the rate of respiration during this period, the greater was the decrease in rate after midnight. Following sunny days this change in rate did not occur; there was no significant drop in the rate of respiration after midnight. In one instance it increased at 29° C. This increase may have been due to a leak developing during the determination that escaped detection, or possibly the rate actually increased.

An obvious explanation of the change in rate of respiration following cloudy days is that the amount of respirable carbon compounds was

a limiting factor. On the basis of this hypothesis the respiration proceeded at a rate determined in part by temperature, and the higher the rate the sooner the supply of respirable material approached exhaustion and the sooner the rate declined. This did not occur after sunny days in spite of the higher initial rates of respiration, simply because of the greater supply of available photosynthate. The data are too meager to establish this hypothesis, but whatever the explanation may be, it is clear that the intensity of light during the day influenced the rate of respiration during the night.

In spite of the variations due to light and other causes, there is a general upward trend to most of the temperature-respiration curves of Figure 11. The one conspicuous exception, May 15, when the rate fell off at 29°, may have been due to low light intensity. The generalization is, then, conclusively established that within the range of temperature here studied, under incubator conditions, the higher the temperature the greater was the rate of respiration in the above-ground part of the plant.

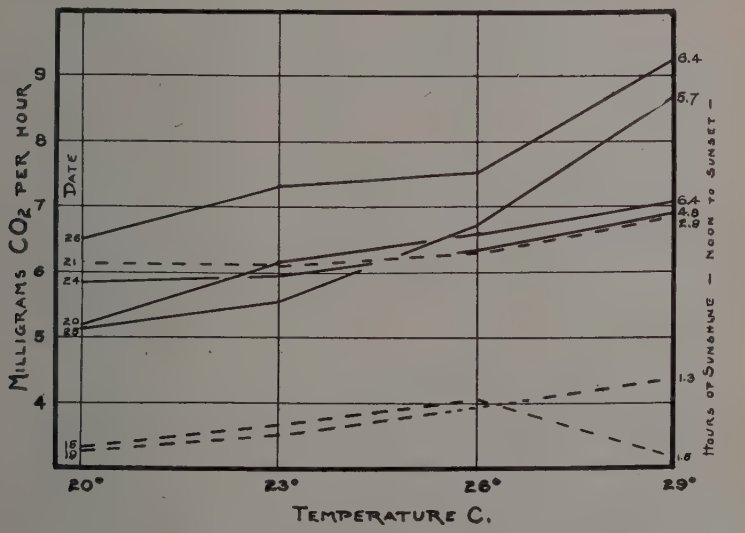


Fig. 11. Selected Data Showing Relation of Sunshine During Afternoon to Rate of Respiration the Following Night

Solid lines indicate sunny days; broken lines, cloudy days.

Carbohydrate determinations.—In these analyses the aim was to find the effect of temperature on the amount of respirable carbohydrate. The samples were therefore taken about sunset on days of bright light, May 20 and 26. The results are given in Table VIII. A conspicuous feature of these data is the consistently higher sugar content in the plants at 20° and 26° than at 23° and 29° C. Probably this was not

a temperature effect but due to differences in light, for in the arrangement of the chambers the 20° and 26°—those with the high carbohydrate content—were at the ends. (See Fig. 2.) They were purposely arranged in this order to check against variations arising from position that might have been interpreted as temperature effects if the chambers had been placed in a simple order of increasing temperature. As the data show a higher carbohydrate content in the end chambers, either these temperatures were more favorable to photosynthesis than 23° or 29°, or temperature effect was masked by some more important factor related to position—probably light.

TABLE VIII

Carbohydrates After Sunny Days
Calculated on a Basis of Ten Grams of Green Weight
Sugar values expressed as milligrams of glucose

Date	Temp. C.	Dry matter	Reducing sugar	Sucrose	Polysaccharides	Total
			Leaflets			
May 20, 8 p.m.	20°	1.011	7.5	12.2	15.3	35.0
	23°	0.947	6.7	6.8	11.3	24.8
	26°	0.960	12.1	10.7	13.7	36.5
	29°	0.830	7.9	7.4	9.9	25.2
May 26, 5 p.m.	20°	1.232	23.6	24.5	83.5	131.6
	23°	1.038	11.0	13.2	64.0	88.2
	26°	1.203	16.0	16.6	81.9	114.5
	29°	1.116	12.4	17.3	62.6	92.3
May 26, 6:30 p.m.	20°	1.139	7.7	22.6	78.4	108.7
	23°	1.065	7.0	13.7	66.2	86.9
	26°	1.117	20.3	14.4	70.0	104.7
	29°	1.106	13.0	13.7	58.6	85.3
			Stems and Petioles			
May 20, 8 p.m.	20°	0.495	21.0	7.6	24.0	52.6
	23°	0.432	14.4	6.2	23.2	43.8
	26°	0.478	20.0	7.4	25.2	52.6
	29°	0.403	12.6	5.4	20.1	38.1
May 26, 6:30 p.m.	20°	0.597	23.1	15.3	38.6	77.0
	23°	0.540	12.4	13.0	30.1	55.5
	26°	0.603	19.0	14.1	42.1	75.2
	29°	0.527	10.3	13.4	30.5	54.2

The evidence that light entered as a limiting factor, combined with similar evidence from the respiration data, suggests that light variations may in part account for the variations in the chemical determinations. The light was not uniform in all parts of the chambers because of shadows from the sash bars. Altho precautions were taken in both respiration and carbohydrate determinations to select plants from the same position in their respective chambers, there was undoubtedly considerable difference in the shading, and as a result differences were present that were not entirely temperature effects.

However, by assuming that the light in the two center chambers was the same, and comparing the carbohydrates in the plants at

23° with those at 29°, no conspicuous difference is evident in the carbohydrate content of either the leaves or stems. The polysaccharides hydrolyzed by one per cent hydrochloric acid are slightly lower at 29°, but the soluble sugars are slightly higher, and the totals therefore are not significantly different. Comparing the results from the two end chambers, operating at 20° and 26°, the conclusions are very similar; the differences are small. This interpretation leads to the general conclusion that the readily available carbohydrate content of the above-ground parts of these plants after a sunny day was not appreciably affected by this range of temperature.

TABLE IX

CARBOHYDRATES AT SUNRISE, MAY 27

Sugar values expressed in milligrams of glucose per ten grams of green weight

Temp. C.	Dry matter	Reducing sugar	Sucrose	Polysaccharides	Total
		Leaflets			
20°	1.175	8.2	1.1	40.0	49.3
23°	1.046	6.3	2.7	31.0	39.0
26°	1.174	4.5	12.2	41.0	57.7
29°	1.140	7.5	4.8	37.1	49.4
		Stems and Petioles			
20°	0.510	16.8	7.7	35.6	60.1
23°	0.448	4.5	3.1	29.9	37.5
26°	0.624	10.6	18.0	43.0	65.6
29°	0.486	6.3	5.3	30.8	42.4

To get a conception of the carbohydrates translocated during the night, the plants used for the respiration measurements of May 26 were sampled at the close of the determination, at sunrise May 27. They were sampled and analyzed in the same manner as the plants of the preceding evening, except that only one plant from each chamber was taken for the sample. A comparison of the analyses at sunrise, in Table IX, with those of the preceding evening, as presented in Table X, shows that about half of the carbohydrates of the leaves were lost during the night, and in the stems only a small reduction in carbohydrates took place. Here, again, the temperature effect is not conspicuous. The differences, representing the carbohydrate translocated and respired during the night, are somewhat greater at the lower temperatures, but are complicated by the variations present in the evening. Altho the data are meager, they indicate that utilization of carbohydrates during the night in translocation plus respiration proceeds somewhat more rapidly at the lower temperatures. But the differences are small and not so outstanding as the fact that a considerable quantity of readily available carbohydrate was present in the leaves and stems at sunrise at all of these temperatures.

TABLE X

COMPARISON OF CARBOHYDRATES AT SUNSET AND SUNRISE
From Data of Tables VIII and IX

Temp. C.	Total carbohydrate 6:30 p.m.	5:00 a.m.	Difference
	Leaflets		
20°	108.7	49.3	59.4
23°	86.9	39.0	47.9
26°	104.7	57.7	47.0
29°	85.3	49.4	35.9
	Stems and Petioles		
20°	77.0	60.1	16.9
23°	55.5	37.5	18.0
26°	75.2	65.6	9.6
29°	54.2	42.4	11.8

The slow translocation can not be attributed to the artificial environment. Davis and Sawyer (7) reported similar data from plants growing in the field. Their analyses were of plants at an early stage of development, probably comparable to those used here, but at an average temperature nearer the optimum for tuber growth, about 15° C. Furthermore, they used larger samples and separated the different carbohydrates in greater detail. When summarized, as in Table XI, their data show a very small difference between the sum of the carbohydrates at sunset and sunrise. Altho their data on a dry weight basis are not readily comparable with the figures above from a green weight basis, and neither gives the absolute amounts, the results do show that the leaves and stems contain a relatively high percentage of soluble and hydrolyzable carbohydrate at sunrise, indicating that a correspondingly small percentage has been translocated and respired during the night.

TABLE XI

CARBOHYDRATES AT SUNSET AND SUNRISE, DATA OF DAVIS AND SAWYER (7)
Values expressed in percentage of dry matter

	Leaflets		Stems	
	At 8 p.m.	At 4 a.m.	At 8 p.m.	At 4 a.m.*
Hexoses	1.22	0.15	5.63	4.30
Sucrose	2.73	1.76	3.57	2.34
Pentose	0.42	0.43	0.53	0.82
Pentosan	5.51	5.70	12.15	12.08
Starch	1.61	1.33	0.13	0.78
Soluble starch	0.36	0.00	...	...
Total	11.85	9.37	22.01	20.32
Loss during night		2.48		1.69
Expressed in per cent		20.9		7.7

* Davis and Sawyer made no analyses of stems sampled at 4 a.m. These figures are calculated by extrapolation from analyses of 2 a.m.

Relation of respirable carbohydrate to respiration.—The carbohydrates reported in the preceding analyses can not be quantitatively compared with the respiration, for the carbohydrate samples included only a portion of the leaves and stems while the respiration figures are based on the entire above-ground parts. However, comparative calculations are interesting and show more clearly the importance of respiration to carbohydrate storage. For a standard of comparison, the data in Table XII have been calculated on a basis of ten grams of green weight of leaflets and the carbon dioxide of respiration (from Table VI) is reduced to its glucose equivalent. To secure a representative fraction of the entire top based on ten grams of leaflets, it was necessary to include somewhat more than twenty grams of stems. The actual weight of stem corresponding to ten grams of leaflets for each sample is shown in the table. Here the decrease in carbohydrate in the leaflets during the night is added to the decrease in the stems, and the totals are compared to the respiration.

TABLE XII

RELATION OF RESPIRATION TO CARBOHYDRATE LOST FROM LEAVES AND STEMS DURING THE NIGHT OF MAY 26-27

All values calculated to a basis of ten grams of green leaflets

Temperature	20° C.	23° C.	26° C.	29° C.
Leaflets				
Total carbohydrate at 6:30 p.m., mgm.	108.7	86.9	104.7	85.3
5:00 a.m.	49.3	39.0	57.7	49.4
Decrease	59.4	47.9	47.0	35.9
Stems and Petioles				
Weight per 10 gm. leaflets at 6:30 p.m. gm.	21.7	22.0	24.5	28.2
5:00 a.m.	23.8	24.6	25.6	28.7
Total carbohydrate at 6:30 p.m. mgm.	167.0	122.1	184.0	152.8
5:00 a.m.	143.1	92.3	167.9	121.5
Decrease	23.9	29.8	16.1	31.3
Total decrease—carbohydrate lost from the above-ground parts during the night	83.3	77.7	63.1	67.2
Respiration. Glucose equivalent	44.6	50.0	51.2	63.1
Percentage of total decrease	53.5	64.4	81.0	93.9

The respiration during the night, as indicated by these calculations, accounts for 53 to 94 per cent, according to temperature, of the decrease in the carbohydrates from sunset to sunrise. The temperature effect is conspicuous. The balance left for growth and storage is about 46 per cent at 20° and only 6 per cent at 29° C. In other words, the carbohydrate available for growth and storage during this night was more than seven times greater at 20° C. than at 29° C.

Even tho these calculations are only approximations, they are strong evidence supporting the view that the detrimental effect of high temperature on tuber growth in the potato is in a large measure due to losses of carbon through respiration.

DISCUSSION

The general inter-relationship between temperature, photosynthesis, respiration, and translocation, found in these studies, is graphically summarized in Figure 12. The two curves of this graph are smoothed averages of data illustrating the physiological situation during the night. The straight line represents the difference between the carbohydrate found in leaves and stems at sunset and at sunrise—the carbohydrate lost from the tops during the night. The ascending curve represents the carbohydrate equivalent of the respiration during the same period. The carbohydrates translocated for growth and storage at a given temperature are then represented by the distance between the two curves at that temperature.

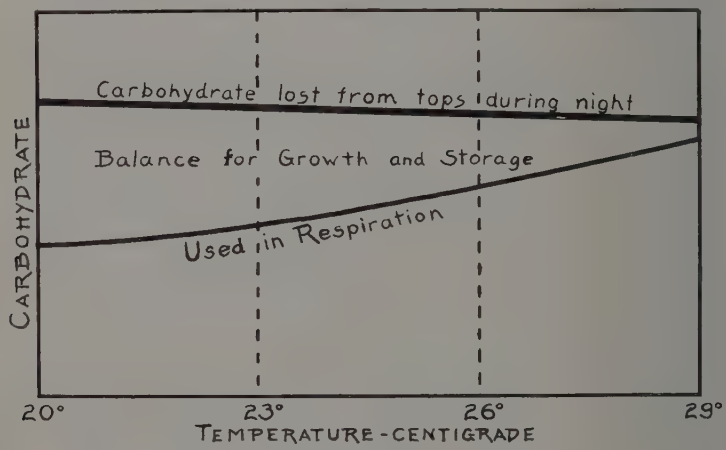


Fig. 12. Relation of Respiration to Total Photosynthate Moved from the Leaves and Stems During the Night

The importance of this inter-relation lies in the fact that the curve of carbohydrate available for growth and storage, as shown by this graph, roughly fits the curve of tuber growth. This fit suggests that tuber growth is directly related to the available carbohydrate.

The data from which these curves were drawn treat only of the situation during the night. No analyses were made during the day except those at sunrise and sunset. In these there was no significant temperature effect; the accumulation of carbohydrate in the leaves and stems during the day was approximately the same at 20° as at 29° C. This fact may be taken to indicate that photosynthesis was also unaffected by temperature. As studies on photosynthesis in other species have shown that deficiency of carbon dioxide or deficiency of light may be limiting factors, it is entirely probable that photosynthesis was limited here, and consequently the total carbohydrate produced during

the day may have been approximately the same throughout this range of temperature. If photosynthesis was thus limited, and if respiration increased with temperature, as it did at night, then the general relation illustrated in Figure 12 may apply to the period of daylight as well as the period of darkness.

This view re-emphasizes the importance of the carbohydrates in relation to the rate of tuber growth. The deficiency of carbohydrate was very probably the limiting factor at these temperatures.

In a generalized form this hypothesis may have wide application in plant physiology. Considerable literature supports the view that deficiency of carbohydrate may be a limiting factor in growth of plants at temperatures above the optimum. The evidence is not direct and conclusive, but falls into three significant lines: (1) Respiration increases with temperature. (2) Photosynthesis is not continuously a function of temperature, deficiency of available carbon dioxide entering at some point as a limiting factor. (3) At high temperatures the carbohydrate content of plants is relatively low. These three facts point to the generalization that deficiency of carbohydrate is a limiting factor in growth of plants at high temperatures.

In studies carried on under artificial conditions the question arises: How far are the conclusions applicable to field conditions? In the case of the potato, the growth under ordinary greenhouse culture appears to be in every way normal. But under the incubator conditions used here, the plants were more spindling than normal, indicating a deficiency of light. It is very probable that the two layers of glass and the shade of the sash bars reduced the light below the optimum for photosynthesis. It is also possible that respiration was abnormally high, as suggested by Brown and Escombe (5). Either of these conditions would reduce the carbohydrate available for growth and storage, and thus reduce tuber growth. In the field there is probably more growth at these temperatures than occurred in the chambers. Thus, in the field, some tuber growth may occur at 29° C., altho none occurred in the chambers at this temperature. A further point to be considered is that this experiment dealt only with young plants. It is possible that older plants would not be so sensitive to temperature. But even taking into consideration these possibilities, the evidence still points to deficiency of carbohydrate as a limiting factor in tuber production at temperatures above the optimum, in the field as well as in the greenhouse.

IV. SUMMARY

1. Evidence in the literature dealing with the relation of temperature to potato yields indicates: (a) The optimum temperature for tuber yield is near 17° C. (b) Above 17° C. yields rapidly decrease with increase in temperature. (c) The detrimental effect of high temperature is largely independent of moisture.

2. In the experiment reported here, potato plants were grown in thermoregulated chambers set to operate at 20°, 23°, 26°, and 29° C.—a range of temperature above the optimum.

3. The plants showed conspicuous responses in the leaves and in the tubers, both decreasing in size with increase in temperature. At 29° no tubers formed. The maximum temperature for tuber growth under these conditions was thus between 26° and 29° C.

4. Respiration during the night in the above-ground part of the plant increased with temperature.

5. The carbohydrate content of leaves and stems, sampled at both sunset and sunrise, was not appreciably affected by this range of temperature.

6. The reduction in the carbohydrate available for translocation which resulted from the increased respiration at the higher temperatures, roughly corresponded to the reduction in tuber growth. Thus, the rate of tuber growth appeared to be a function of the available carbohydrate.

7. From these data, together with evidence from the literature, the suggestion is made that deficiency of carbohydrate arising from excessive respiration may be very generally the limiting factor in plant growth at temperatures above the optimum.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation of the helpful advice and stimulating interest of Dr. R. B. Harvey and Dr. J. J. Willaman, of the University of Minnesota, and Dr. C. A. Shull, of the University of Chicago.

LITERATURE CITED

1. Association of Official Agricultural Chemists. Methods of analysis. Washington. 1921.
2. Bigelow, F. H. The daily normal temperature and the daily normal precipitation of the United States. U. S. Dept. of Agr. Weather Bur. Bul. R. 1908.
3. Blackman, F. F. Optima and limiting factors. Ann. Bot. 19:281-95. 1905.
4. Brown, H. T. and Escombe, F. The influence of varying amounts of carbon dioxide in the air on the photosynthetic process of leaves and on the mode of growth of plants. Proc. Roy. Soc. 70B:397-413. 1902.

5. ————. Researches on some of the physiological processes of green leaves with special reference to the interchange of energy between the leaf and its surroundings. Proc. Roy. Soc. **76B**:29-111. 1905.
6. Bushnell, J. Variation in vigor of sprouts from quarters of single tubers. Bot. Gaz. **78**:233-36. 1924.
7. Davis, W. A. and Sawyer, G. C. Studies of the formation and translocation of carbohydrates of plants. III. The carbohydrates of the leaf and leaf-stalk of the potato. The mechanism of the degradation of starch in the leaf. Jour. Agr. Sci. **7**:352-84. 1916.
8. Fitch, C. L. Studies of health in potatoes. Colo. Agr. Exp. Sta. Bul. 216. 1915.
9. Hardenburg, E. V. Ecological factors affecting tuber-set in potatoes. Proc. Pot. Assoc. Am. **10**:165-72. 1923.
10. Jones, L. R., McKinney, H. H., and Fellows, H. The influence of soil temperature on potato scab. Wis. Agr. Exp. Sta. Res. Bul. 53. 1922.
11. Jost, L. Über die Reaktionsgeschwindigkeit im Organismus. Biol. Centralblatt. **26**:225-44. 1906.
12. Kanitz, A. Temperatur und Lebensvorgänge. 175 p. Berlin. 1915.
13. Klotz, L. J. Studies in the physiology of the fungi. XVI. Some aspects of nitrogen metabolism in fungi. Ann. Mo. Bot. Gard. **10**:299-368. 1923.
14. Lehenbauer, P. A. Growth of maize seedlings in relation to temperature. Physiol. Researches **1**:247-88. 1914.
15. Livingston, B. E. and Shreve, F. The distribution of vegetation in the United States, as related to climatic conditions. Carnegie Inst. Pub. 284. 1921.
16. Marvin, C. F. Psychrometric tables. U. S. Dept. of Agr. Weather Bur. Bul. 1915.
17. Matthaei, G. L. C. Experimental researches on vegetable assimilation and respiration. III. On the effect of temperature on carbon-dioxyd assimilation. Trans. Roy. Soc. **197B**:47-105. 1904.
18. Orton, W. A. Environmental influences in the pathology of *Solanum tuberosum*. Jour. Wash. Acad. Sci. **3**:180-90. 1913.
19. Richards, B. L. Pathogenicity of *Corticium vagum* on the potato as affected by soil temperature. Jour. Agr. Res. **21**:459-82. 1921.
20. Shaffer, B. A. and Hartmann, A. F. The iodometric determination of copper and its use in sugar analysis. II. Methods for the determination of reducing sugars in blood, urine, milk, and other solutions. Jour. Biol. Chem. **45**:365-90. 1921.
21. Smith, J. W. The effect of weather upon the yield of potatoes. Mon. Weather Rev. **43**:222-36. 1915.
22. Spoehr, H. A. and McGee, J. M. Studies in plant respiration and photosynthesis. Carnegie Inst. Pub. 325. 1923.
23. Tottingham, W. E. Temperature effects in plant metabolism. Jour. Agr. Res. **25**:13-30. 1923.
24. Truog, E. Method for the determination of carbon dioxide and a new form of absorption tower adapted to the titrimetric method. Jour. Ind. and Eng. Chem. **7**:1045-49. 1915.
25. U. S. Dept. of Agr. Yearbook. 1923.
26 Walster, H. L. Formative effect of high and low temperatures upon growth of barley: a chemical correlation. Bot. Gaz. **69**:97-126. 1920.

ECHNICAL BULLETIN 35 DECEMBER 1925

University of Minnesota
Agricultural Experiment Station

Physiologic Specialization in Puccinia graminis avenae Erikss. and Henn.

Dixon L. Bailey
Division of Plant Pathology and Botany

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	3
Historical summary	3
Object of present investigation	5
Methods and materials	6
Classes of host reaction and infection types	6
Identification of physiologic forms	7
Experimental results	8
Field tests of oat varieties	26
Geographical distribution	28
Discussion and conclusion	30
Summary	31
Literature cited	32
Explanation of plates	34
Plates	36

PHYSIOLOGIC SPECIALIZATION IN PUCCINIA GRAMINIS AVENAE ERIKSS. AND HENN.[1]

DIXON L. BAILEY

INTRODUCTION

The over-shadowing importance of the wheat stem rust problem, together with the failure for a long time to demonstrate the existence of physiologic forms of *Puccinia graminis avenae* Erikss. and Henn. on oats, resulted to some extent in the neglect of the oat rust problem. The apparently ever-increasing economic importance of stem rust of oats, together with the demonstration of physiologic specialization in *P. graminis avenae* Erikss, and Henn. by Stakman, Levine, and Bailey (33) in 1923, has given added interest and a new significance to the problem, and has been largely responsible for the present investigation.[2]

HISTORICAL SUMMARY

It is questionable whether any other single event in the history of plant pathology has had so far-reaching an influence on the development of cereal pathology as the demonstration of physiologic specialization in *Puccinia graminis* Pers. by Eriksson (4)[3] in 1894. Much intensive work has been done on the subject since that time, with the result that our knowledge of the phenomenon has been increased to such an extent that today the significance of physiologic specialization is appreciated everywhere by those engaged in cereal rust investigations. This physiologic specialization is of the utmost importance, not only to a proper understanding of the parasitic behavior of rust fungi, but to the effective control of their ravages, as well.

A detailed review of the general field of physiologic specialization has been made by Reed (26), and a careful review of specialization in the cereal rusts by Stakman (28), Newton (23), and others. Therefore it seems unnecessary to do more here than merely to outline the significant advances which have led to our knowledge of specialization in cereal rusts.

[1] This investigation was a continuation of work done while the author was a member of the staff of the Office of Cereal Investigations, and of the Minnesota Agricultural Experiment Station.

This paper was submitted to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, June, 1924.

[2] The writer wishes to express his appreciation of much help received from Dr. E. C. Stakman and Dr. M. N. Levine; as well as of the kindness of Mr. T. R. Stanton, Cereal Investigations, Bureau of Plant Industry, Washington, D. C.; and the Agronomy Department, University of Minnesota, in supplying seed of oat varieties. Dr. Alfred Savage, of Manitoba Agricultural College, also rendered much assistance in the preparation of the plates.

[3] Reference is made by number to "Literature cited," page 32.

For almost a century after it was described by Persoon, the stem rust organism, *Puccinia graminis,* was regarded as a single species capable of attacking all the common cereals and grasses. But in 1894 Eriksson (4), showed definitely that this single species comprised several distinct, physiologically specialized races, each limited in infection capabilities to a definite and distinctive group of cereals and grasses. Six such races, or varieties, of *P. graminis* have been found to occur on the North American continent, and are designated as follows: *Puccinia graminis tritici; P. graminis secalis; P. graminis avenae; P. graminis phlcipratensis; P. graminis agrostis;* and *P. graminis poae.* They have come to be known as the six major physiologic forms, or recently as varieties of *P. graminis.*

Since 1894 many investigators have studied the physiologic specialization of *P. graminis.* In Europe, Eriksson (4, 5), Eriksson and Henning (6), Ward (40, 41), Jaczewski (16), and Vavilov (39) have been outstanding; while in America, Hitchcock and Carleton (12), Carleton (2, 3), Freeman and Johnson (9), Johnson (17), Stakman (28) Stakman and Piemeisel (37), Stakman and Levine (32), Fraser (7), Newton (23), Levine (19), and others have contributed much to our knowledge of the subject.

Much of the earlier work dealt largely with the host range and constancy of the several physiologic forms. In 1916, however, Stakman and Piemeisel (36) showed that further specialization existed within *P. graminis tritici.* Subsequent research on the specialization of *P. graminis* has dealt in the main with these component physiologic forms. The most extensive work has been done by Stakman and Levine and their co-workers (18-21, 28-38), at the University of Minnesota, in co-operation with the United States Department of Agriculture. These investigators have demonstrated (32) the existence of at least 37 physiologic forms of *P. graminis tritici,* distinguished by their action on twelve wheat varieties. A limited number of forms of *P. graminis secalis* and *P. graminis avenae* on varieties of rye and oats have also been demonstrated (21, 33).

The physiologic specialization of several other species of rust fungi also has been investigated, and has been found to be of wide occurrence. It was demonstrated in *P. coronata avenae* Cda. by Hoerner (13, 14) in 1919; in *P. triticina* Erikss., in 1921 by Mains and Jackson (22); and in *P. glumarum* previously by Eriksson (4) and in 1923 by Hungerford and Owens (15).

The extent of the investigations on physiologic specialization is sufficient evidence of the importance of the subject. Indeed, as the development of resistant varieties is one of the most promising methods

of combating cereal rusts in general, it is evident that, in each particular case, the solution of a rust problem requires a thoro investigation of the physiologic specialization of the causal organism. Only in this way can resistant varieties be chosen or developed with any assurance that their resistance will be adequate in all localities and at all times.

OBJECTS OF PRESENT INVESTIGATION

The present investigation of physiologic specialization in *P. graminis avenae* and its relation to the oat stem rust problem in general, was practically a continuation of the investigations begun by Stakman, Levine, and Bailey and reported by them (33) in 1923. The apparently increasing destructiveness of stem rust of oats in the last few years made it desirable to know more of the nature and occurrence of the forms of *P. graminis avenae,* so that resistant varieties of oats could be developed.

Accordingly, extensive collections of stem rust on oats have been obtained and cultivated in the greenhouse. The reaction of a large number of varieties to these cultures has been determined. The physiologic forms isolated on the basis of their effect on the differential varieties have been carefully studied and are reported on here.

METHODS AND MATERIALS

Differential hosts.—The selection of differential hosts was difficult. More than a hundred varieties of oats, belonging to six species of the genus *Avena,* were tested as differentials; and from this number only six differential hosts were obtained. Five of these, namely: Richland (C.I. 787) and the pure line isolations from Monarch Selection (C.I. 1879), Joanette (C.I. 1880), and the Heigira Rustproof (C.I. 1001), and Strain 703, belong to *Avena sativa,* while the sixth, White Tartar (C.I. 551) is a variety of *Avena orientalis.* While all six of these lines are differential, it appears from results to date that some of them are identical in resistance and that they really represent only three groups of differentials, as follows: (1) Joanette and Strain 703; (2) Richland, Heigira Rustproof, and Monarch Selection; and (3) White Tartar.

The first of the pure lines to be obtained, which is designated throughout this work as "Strain 703," apparently originated from the Monarch Selection of Etheridge. Indeed, it was thought to be identical with Monarch Selection until the original supply of seed was practically exhausted and additional lots of seed were obtained from different sources. In general, the plants grown from these lots of seed were entirely susceptible. Resistant plants of the original sample were

therefore selected as the basis of a pure-line differential host. This line has been designated simply as Strain 703, after the nursery row number under which it originally came to us.

The variety Joanette (C.I. 1880) also was found to contain pure lines of differential value, altho, like Strain 703, the stock material was not genetically pure in its resistance, and the differential line had to be developed from selected plants of known resistance. Several samples of Joanette were obtained which were wholly without resistance, and the origin of the differential line is unknown. In its reaction, the selected line, henceforth designated as Joanette Strain, is apparently identical with Strain 703.

An occasional plant in a sample of Monarch Selection (C.I. 1879) received from the Office of Cereal Investigations, United States Department of Agriculture, was found to react differently to different cultures of *P. graminis avenae*. A few of these plants, chosen on the basis of their resistance, were increased to serve as a possible differential line. The name "Monarch Strain" was chosen for this line to distinguish it from the Monarch Selection of Etheridge, which was used as a differential variety in previous work (33). The name "Monarch Strain," however, is more indicative of its origin than of its nature, as the bulk of Monarch Selection seems to be altogether without resistance. Monarch Strain differs very little in its reaction from Richland and Heigira Rustproof and may for the present be included with them as one differential group.

As about five per cent of the plants of Heigira Rustproof (C.I. 1001) were without resistance, it was necessary to select a pure line differential of this variety also, to be known from now on as "Heigira Strain." This strain, however, was not different in its reaction to the various forms of *P. graminis avenae* from Monarch Strain and Richland, the three constituting a single differential group.

Lines of satisfactory purity of the remaining differentials, Richland (C.I. 787, Iowa 105) and White Tartar (White Russian) (C.I. 551, Minn. 339), were available without selection.

Progress of the work was much retarded by the necessity of developing pure lines of the various differential hosts. Even yet the amount of available seed of Monarch Strain and of Strain 703 is so limited that it often has not been possible to use nearly as many plants as was desired.

CLASSES OF HOST REACTION AND INFECTION TYPES

The classes and sub-classes of host reaction as well as the infection types indicated by Stakman, Levine, and Bailey (33) have been followed. These are as follows:

Classes of Host Reaction	Types of Rust Infection
Practically immune	0. No uredinia developed, but sharply defined hypersensitive flecks present.
Extremely resistant	1. Infection very light; uredinia minute, scattered, and surrounded by sharply defined necrotic areas.
Moderately resistant	2. Infection light; uredinia usually small and scattered, hypersensitive areas varying from sharply defined necrosis to pronounced chlorosis.
Moderately susceptible	3. Infection moderate; uredinia mid-sized with a tendency to coalesce; true hypersensitiveness absent, but more or less well marked chlorosis present.
Completely susceptible	4. Infection normal and heavy; uredinia large, numerous, and confluent; hypersensitiveness absent, but chlorosis may be present.
Indeterminate	X. Uredinia very variable, apparently including all types of infection, often on the same leaf blade; no mechanical separation of the types seems possible, and the infection in general is ill-defined and heterogeneous.

These types of infection are illustrated in Plate 1, and a more detailed description of their characteristics and variability is included in the subsequent discussion of the individual forms.

IDENTIFICATION OF PHYSIOLOGIC FORMS

An analytical key to the physiologic forms of *P. graminis avenae*, which serves to identify the individual forms by the reaction of the above mentioned differential hosts, is given in Table I.

TABLE I

ANALYTICAL KEY FOR IDENTIFICATION OF PHYSIOLOGIC FORMS OF *P. graminis avenae*

Infection homogeneous on all differential hosts	
White Tartar resistant	
Joanette Strain resistant	Form 1
Joanette Strain susceptible	Form 2
White Tartar susceptible	
Richland resistant	Form 3
Richland susceptible	Form 4
Infection heterogeneous on some differential hosts	
Joanette Strain indeterminate	Form 5

EXPERIMENTAL RESULTS

Classification of physiologic forms.—Five physiologic forms of *P. graminis avenae* have been isolated. A summary of the infection characteristics of these forms on six differential hosts and on one control variety is presented in Table II. A discussion of the characteristics of each form follows:

TABLE II

VARIATIONS AND CONSTANTS IN REACTION OF DIFFERENTIAL HOSTS OF AVENA SPP. TO PHYSIOLOGIC FORMS OF *P. graminis avenae*

Physiologic forms	Differential hosts with ranges and means of infection						Control host	
	White Tartar		Joanette Strain and Strain 703		Richland, Monarch and Heigira Strains		Victory	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean
1	2— to 3—cn.	3—	0; to 1++	1	2 to 2++	2	4— to 4++	4
2	2— to 3—cn.	3—	4— to 4+	4	1— to 2++	2	4— to 4++	4
3	3 to 4+	4—	0; to 1	1—	2— to 2++	2	4— to 4++	4
4	4— to 4++	4	0; to 1	1—	4— to 4++	4	4— to 4++	4+
5	2— to 3—cn.	3—	X— to X+	X	1— to 2++	2	4— to 4++	4

Explanation of symbols: Plus and minus signs indicate a slightly greater or less amount of rust than the nearest figure representing the infection type. The semicolon indicates the presence of flecks. —cn. indicates that hypersentiveness ranging from chlorosis to necrosis typically accompanies the infection.

NATURE OF FORMS ISOLATED

Form 1.—This form is singularly lacking in virulence on the differential hosts used. It is incapable of infecting normally any of the differentials except Victory, which, it will be remembered, is equally susceptible to all the physiologic forms and therefore is not really differential. The reaction of the various differential hosts to Form 1 is illustrated in Plate 2.

Strain 703 is extremely resistant to Form 1. Its reaction varies from the production of only sharply necrotic flecks without any uredinia to the production of fairly abundant, small uredinia, each surrounded by a very definite necrotic area. That is, the type of infection varies from 0, with flecks, to 1++. The degree of infection seems to be very largely a reflection of existing environmental conditions. As the light intensity is reduced or the temperature lowered, the infection becomes progressively weaker, until necrotic flecks are the only evidence that infection has taken place. Even under optimum environmental conditions infection is decidedly limited, and belongs in type 1, altho there is a slight increase in the size of the uredinia.

The reaction of Joanette Strain to Form 1 is practically identical with that of Strain 703. At times the range of infection on Joanette seemed somewhat more limited, with the maximum 1 rather than 1+. The difference, however, was not at all striking.

Richland and Heigira Strain are infected to about the same degree by Form 1. The infection is of type 2, with the extreme variations

approaching type 1 and, rarely, type 3. Usually, however, in the weak infections the uredinia are too large for type 1, while in the most vigorous infections hypersensitiveness is too marked for type 3. There is a distinct tendency in Richland, especially when environmental conditions are not optimum, for infected tips to parch and die before uredinia are developed, or about the time they begin to break through the epidermis.

A type 2 infection is characteristic of Monarch Strain when infected by Form 1. The pustules are usually smaller than the average in type 3 infections, but only a moderate chlorosis is associated with the uredinia.

In the infection of White Tartar by Form 1, there is considerable variation in the size of the uredinia. Pustules varying from 3— to 3= are commonly met with. The infection is always accompanied by some chlorosis altho in this respect there is the greatest variation. Sometimes chlorosis is so slight as to be scarcely noticeable except on the upper surface of the leaf; at other times it is so pronounced as to merge almost into necrosis. The variation seems to be associated with the number of uredinia in the infected area as well as with environmental conditions, especially light intensity. Other factors may well be operating, but the reaction is still very imperfectly understood. The chlorosis, instead of delimiting the individual uredinia, is usually diffused.

Generally speaking, Form 1 infects the various differential hosts weakly, and is remarkably constant. One culture, collected in 1921, has been cultured for 40 urediniospore generations. At the end of that time it produced typical infection on all the differential hosts. The history of this particular culture is summed up in Table IV, as an example of the cultural characteristics of Form 1. In view of the limited infection capabilities of Form 1 in relation to the differential varieties, its wide distribution and comparative frequency of occurrence (see Table XIX) seemed difficult to explain. In order to obtain a better idea of its virulence, the reaction of a large number of standard oat varieties to Form 1 was determined. The results are given in Table III, where it will be seen that, even tho Form 1 is conspicuously lacking in virulence with respect to the differential hosts as compared with the other forms, it is nevertheless capable of infecting normally each of the 56 oat varieties tested. Its grass-host range, too (Table XVII), is not, so far as has been investigated, significantly more limited than that of the other forms. Consequently, it seems that Form 1 should be regarded as lacking in virulence only in relation to the three differential groups.

TABLE III

REACTION OF SPECIES AND VARIETIES OF AVENA TO *P. graminis avenae*, FORM 1

Varietal name*	Classification	Plants inoculated	Plants infected†
Avena nuda	*Avena nuda*	12	10
A. strigosa	*A. strigosa*	10	10
A. brevis	*A. brevis*	10	10
A. sterilis nigra	*A. sterilis*	6	5
A. sterilis (selection)	do	10	10
Red Rustproof	do	11	9
Burt	do	9	9
King	do	8	8
Oklahoma 606	do	10	7
Winter Turf	*A. sativa*	8	7
Culbertson	do	12	12
Black Norway	do	14	14
Victor	do	10	9
Monarch	do	10	10
Black Mesdag	do	9	9
Black Diamond	do	12	12
Joanette	do	15	14
C.I. 620	do	14	13
North Finnish	do	14	14
Garkova 473	do	14	12
Garkova 691	do	12	10
Kherson	do	10	9
Kherson selection	do	10	10
60-Day	do	12	10
60-Day Selection	do	14	12
Early Champion	do	14	14
Awnless Probsteier	do	10	9
Japan Selection	do	15	11
Golden Drop	do	12	10
C.I. 603	do	14	12
Green Russian	do	14	14
Monarch Diamond	do	10	9
Canadian	do	10	10
Tobolsk	do	12	10
Early Dakota	do	14	14
Irish Victor	do	12	10
Danish Island	do	9	8
Early Gothland	do	14	12
Belyak	do	14	14
Silvermine	do	10	10
Scottish Chief	do	12	12
June	do	12	12
Swedish Select	do	13	11
Lincoln	do	12	12
Golden Rain	do	10	10
Banner	do	12	12
Ligowa	do	21	16
Garton 748	*A. orientalis*	10	10
Garton 84	do	10	10
Garton Gray	do	12	10
Black Tartarian	do	14	12
Golden Giant	do	14	14
Sparrowbill	do	12	12
Garton 585	do	12	12
Tartar King	do	12	10
Storm King	do	12	11

* The U. S. Department of Agriculture Cereal Investigation numbers are omitted, as they are given in Table XVII.

† Infection type 4 throughout, except first 3 species on which the rust produced a type 3 infection.

Form 2.—Form 2 is distinguished from Form 1 only by the reactions of Strain 703 and Joanette Strain. These differentials are completely susceptible instead of being resistant, as they are to Form 1. When these hosts are inoculated with Form 2, numerous large, vigorous uredinia develop, which commonly coalesce. As a rule there is no associated chlorosis, altho occasionally a slight amount is present, especially if the infection is very heavy. As this phenomenon is common in the majority of thoroly susceptible varieties, it seems not to have any particular significance here.

The other differentials—White Tartar, Monarch Strain, Heigira Strain and Richland—are all resistant to Form 2. Their various reactions to Form 2 apparently are identical with those to Form 1. The reaction of all the differential hosts to Form 2 is illustrated in Plate 3.

Form 2 was found to infect all the oat varieties which were tested with Form 1 (See Table III). All the varieties were so susceptible and the infections so uniform that it seems undesirable to record the details. The infection capabilities of one collection of Form 2 have remained unchanged through 29 urediniospore generations. A summarized cultural history of a collection of Form 2 is given in Table IV.

Form 3.—Form 3 is similar to Form 1, except for the reaction of White Tartar, which is susceptible to Form 3. Therefore with Form 3 we have the varieties Victory and White Tartar completely susceptible; while Joanette Strain and Strain 703 on the one hand, and Richland, Heigira Strain, and Monarch Strain on the other, are still very resistant. The last three hosts react to Form 3 in much the same way as to Forms 1 and 2, the reaction being some variation of type 2. Joanette Strain and Strain 703 are quite as resistant to Form 3 as to Form 1. The infection characteristics of Form 3 are illustrated in Plate 4.

Only two collections of Form 3 have been obtained, and neither of these was of American origin. One was collected by E. C. Stakman in Sweden (Upsala) and the other by G. F. Puttick in South Africa (Potchefstroom, Transvaal) (33). The cultural history of the South African collection is given in Table IV.

Form 4.—This is an exceedingly virulent form to which all the differential hosts except Joanette Strain and Strain 703, are completely susceptible. Even Heigira Strain, Richland, and Monarch Strain, resistant to all the other forms, are infected by Form 4 as heavily as is Victory, which is susceptible to all the forms.

Form 4 is represented by a single culture, collected by Stakman at Upsala, Sweden. Its cultural history is given in Table IV. The reaction of the various differential hosts to Form 4 is shown in Plate 5.

Form 5.—The most characteristic reaction of Form 5 is the heterogeneous type of infection which develops on Joanette Strain and

Strain 703 when infected by it. This type of infection is shown in Plate 1, F. It is characterized by the great variability both in pustule size and in degree of hypersensitiveness, which is found on even a single infected leaf. All types of infection from 1 to 4 are commonly found on the same leaf, with a hypersensitiveness which may vary from a faint chlorosis to a sharp necrosis also usually present. The different types of infection are not separable by the ordinary method of mechanical separation. Transfers from any particular type usually result in all the infection types from 1 to 4 occurring again in the subsequent infection. This seems to indicate that the form is not a mechanical mixture of several forms.

In order to ascertain whether Form 5 was a mixture of other forms, a monosporous culture was obtained. Single spores were picked up directly from a dry slide on a needle very slightly smeared with vaseline, a No. 2 eyepiece and low-power objective being used during the process. A single spore was transferred to a seedling and the inoculated plants were then incubated as usual. Scarcely more than one half of one per cent of the inoculated leaves became infected.

Only one such single-spore culture has yet been compared with the original strain. In this case, what seems to be a perfectly typical culture of Form 2 was isolated. Strain 703 and Joanette Strain have been completely susceptible to the single-spore strain for two uredinio-spore generations, while the original strain continues to produce the same heterogeneous infection on these varieties. Further trials are in progress. It is recognized that a single trial does not warrant drawing any general conclusions. The indication is, however, that Form 5 may be a mixture of Form 2 and another form from which it is separated only with very great difficulty. Even if this be the case there probably is a fifth form present, because the other four forms produce infection of either type 1 or type 4 on Joanette Strain and Strain 703, and this leaves the intermediate types which are present in the X reaction unaccounted for. The final clearing up of the problem must await more extended investigations.

The summarized history of a culture of Form 5 is given in Table IV and is illustrated in Plate 6.

TABLE IV

PARASITIC BEHAVIOR OF TYPICAL CULTURES OF FIVE PHYSIOLOGIC FORMS OF *P. graminis avenae*

Subject matter	Host reaction			
	Differential hosts			Control host
	White Tartar	Joanette Strain and Strain 703	Richland, Monarch, and Heigira Strains	Victory
	P. graminis avenae, Form 1 Collected Aug. 12, 1921, on Victory oats at St. Paul, Minn.			
Number of trials....	12	11	9	26
Plants inoculated ...	150	105	113	315
Plants infected	146	96*	113	296
Range of infection...	2— to 3†	0; to 1++	2— to 2+	4 to 4+
	P. graminis avenae, Form 2 Collected Aug. 1, 1923, at Melfort, Sask.			
Number of trials....	1	4	6	8
Plants inoculated ...	17	66	74	89
Plants infected	16	58	70	83
Range of infection...	2— to 3†	4 to 4	2— to 2	4 to 4+
	P. graminis avenae. Form 3 Collected May 11, 1922, at Potchefstroom, South Africa			
Number of trials....	18	5	17	14
Plants inoculated ...	194	78	225	167
Plants infected	185	56	217	150
Range of infection...	3 to 4	0; to 1	2— to 2	4 to 4+
	P. graminis avenae, Form 4 Collected Sept. 14, 1922, at Upsala, Sweden			
Number of trials....	6	7	15	10
Plants inoculated ...	82	91	173	127
Plants infected	78	79	170	122
Range of infection...	4— to 4	1— to 1	4— to 4	4 to 4+
	P. graminis avenae, Form 5 Cellected Aug. 8, 1913, at Morden, Man.			
Number of trials....	2	7	7	5
Plants inoculated ...	27	74	73	54
Plants infected	27	70	66	50
Range of infection...	2— to 3†	X to X+	2— to 2	4 to 4+

* There were also three heavily infected plants, probably due to accidental seed mixture.
† Hypersensitiveness—chlorosis to necrosis—regularly present.

MORPHOLOGICAL DIFFERENCES BETWEEN THE PHYSIOLOGIC FORMS

Levine (19) has shown recently that when the major physiologic forms or varieties of *Puccinia graminis* are developed under identical conditions, each variety is characterized by spore measurements differing significantly from those of other varieties. The morphological identity of minor physiologic forms has been studied heretofore only in an empirical way (31). Consequently, it seemed desirable to study statistically the spore measurements of the urediniospores of the physiologic forms of *P. graminis avenae* in order to determine whether they differ significantly in size. Such a study seemed particularly desirable, as the spores of *P. graminis avenae* have long been recognized as the most variable of any of the varieties of *P. graminis*.

Accordingly, 200 urediniospores of each of Forms 1, 3, 4, and 5 produced on congenial hosts under similar conditions, were measured by means of an ocular micrometer. From the measurements so obtained, the various biometric constants of spore length and spore width were calculated and compared. The results are given in Tables V to VIII inclusive. A study of the tables indicates that there are apparently appreciable and significant differences between the mean spore dimensions of the different forms. For instance, the urediniospores of Form 4 are significantly longer and wider than those of the other three forms. Likewise those of Form 3 seem longer but narrower than those of Forms 5 and 1. The suggestion of a correlation between spore length and virulence is interesting.

TABLE V

FREQUENCY DISTRIBUTION FOR LENGTHS OF 200 UREDINIOSPORES OF *P. graminis avenae* FORMS 1, 3, 4, AND 5, DEVELOPED UNDER IDENTICAL CONDITIONS

Physiologic form	Spore length (in microns) Frequency classes																	Total population	
	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	
1	1	0	1	2	33	13	11	32	62	22	2	4	12	5	0	0	0	0	200
3	3	1	2	6	27	6	17	22	43	19	3	14	14	18	3	1	0	1	200
4	0	0	0	0	9	1	5	15	63	24	2	25	22	22	7	3	0	2	200
5	0	2	1	1	55	21	13	29	45	10	1	13	7	2	0	0	0	0	200

TABLE VI

FREQUENCY DISTRIBUTION FOR WIDTHS OF UREDINIOSPORES OF *P. graminis avenae*, FORMS 1, 3, 4, AND 5, DEVELOPED UNDER IDENTICAL CONDITIONS

Physiologic form	Spore width (in microns) Frequency classes										Total population
	13	14	15	16	17	18	19	20	21	22	
1	0	4	24	36	96	24	7	3	1	5	200
3	23	32	46	35	62	2	0	0	0	0	200
4	2	1	8	22	123	27	12	2	1	2	200
5	12	16	22	46	70	21	5	4	1	3	200

TABLE VII

CONSTANTS OF SPORE DIMENSIONS OF UREDINIOSPORES OF PHYSIOLOGIC FORMS OF *P. graminis avenae*, DEVELOPED UNDER IDENTICAL CONDITIONS

Physiologic form	Spore length (in microns)			Spore width (in microns)		
	Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability
1	29.41±0.12	2.43±0.08	8.2±0.27	16.90±0.07	1.30±0.05	8.2 ± .27
3	30.03±0.15	3.24±0.11	10.7±0.51	15.44±0.07	1.39± .05	9.01±0.42
4	31.50±0.13	2.7 ±0.09	8.6±0.29	17.11±0.05	1.13± .04	6.5 ±0.22
5	28.63±0.14	2.83±0.09	9.6±0.45	16.38±0.08	1.69± .06	10.3 ±0.48

TABLE VIII

SUMMARY OF DIFFERENCES BETWEEN THE MEANS AND COEFFICIENTS OF VARIABILITY OF UREDINIOSPORE DIMENSIONS OF PHYSIOLOGIC FORMS OF *P. graminis avenae* DEVELOPED UNDER IDENTICAL CONDITIONS

Physiologic forms compared	Arithmetical means				Coefficients of variability			
	Length		Width		Length		Width	
	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.
P. graminis avenae 1 and 3....	0.62 ± 0.19	3.26	1.46 ± 0.09	16.22	2.5 ± 0.58	4.31	0.8 ± 0.50	1.60
do 4	2.09 ± 0.18	11.61	0.21 ± 0.07	3.00	0.4 ± 0.39	1.02	1.7 ± 0.34	5.00
do 5	0.78 ± 0.18	4.33	0.52 ± 0.10	5.20	1.4 ± 0.52	2.69	2.1 ± 0.44	4.77
P. graminis avenae 3 and 4....	1.47 ± 0.19	7.73	1.67 ± 0.07	20.87	2.1 ± 0.58	3.62	2.5 ± 0.47	5.32
do 5	1.40 ± 0.20	7.00	0.94 ± 0.10	9.40	1.1 ± 0.68	1.47	1.3 ± 0.63	2.06
P. graminis avenae 4 and 5....	2.87 ± 0.23	12.48	0.73 ± 0.09	8.11	1.0 ± 0.53	1.89	3.8 + 0.48	7.92

TABLE IX

FREQUENCY DISTRIBUTIONS OF SPORE LENGTHS OF UREDINIOSPORES OF A SINGLE-SPORE CULTURE AND OF A BULK CULTURE OF *P. graminis avenae*, FORM 5

Type of culture	Frequency classes for spore length (in microns)												Total population
	24	25	26	27	28	29	30	31	32	33	34	35	
Single-spore culture	3	3	14	6	9	11	31	7	1	6	2	7	100
Bulk culture	0	2	18	3	8	12	34	8	3	6	1	5	100

TABLE X

FREQUENCY DISTRIBUTIONS OF SPORE WIDTH OF UREDINIOSPORES OF A SINGLE-SPORE CULTURE AND OF A BULK CULTURE OF *P. graminis avenae*, Form 5

Type of culture	Frequency classes for spore width (in microns)										Total population
	13	14	15	16	17	18	19	20	21	22	
Single-spore culture ..	2	3	13	15	48	11	6	0	2	0	100
Bulk culture	1	3	13	16	49	11	4	2	0	1	100

TABLE XI

COMPARISON OF CONSTANTS OF SPORE DIMENSIONS OF UREDINIOSPORES OF A BULK AND A MONOSPOROUS CULTURE OF *P. graminis avenae*, Form 5

Type of culture	Constants of spore length			Constants of spore width		
	Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability
Monosporous ...	29.34±0.16	2.45±0.12	8.4±0.40	16.63±0.12	1.34±0.07	8.1±0.39
Bulk	29.44±0.16	2.4 ±0.11	8.1±0.38	16.75±0.12	1.32±0.06	7.8±0.37

A comparison of the coefficients of variability for spore lengths indicates that the urediniospores of Form 3 are somewhat more variable in length than those of Forms 1 and 4. These results suggest that the marked variability of spore size in *P. graminis avenae* is an inherent character and is not due to the mixing of the spores of a number of physiologic forms differing greatly in spore size. This conclusion was substantiated still further by the results of a comparison of spore size and variability of a single-spore culture as compared with a bulk culture of Form 5. In this case one hundred spores of each culture were measured. As will be seen by a study of Tables IX, X, XI and XII, there was no significant difference between the two in either spore length, spore width, or variability.

TABLE XII

DIFFERENCES IN THE MEANS AND COEFFICIENTS OF VARIABILITY OF UREDINIOSPORE DIMENSIONS OF A SINGLE-SPORE CULTURE AND OF A BULK CULTURE OF *P. graminis avenae*—Form 5

Cultures compared	Arithmetical means				Coefficients of variability			
	Length		Width		Length		Width	
	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.
Monosporous and bulk	0.10±.23	0.43	0.12±.17	0.71	0.3±.55	0.55	0.3±.54	0.56

TABLE XIII

FREQUENCY DISTRIBUTION FOR LENGTHS OF UREDINIOSPORES OF PHYSIOLOGIC FORMS OF *P. graminis avenae* DEVELOPED UNDER VARIOUS ENVIRONMENTAL CONDITIONS AND ON DIFFERENT HOST PLANTS

Physiolgoic forms	Conditions	Frequency classes for spore length (in microns)																	Total population	
		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	
Form 1	Resistant host	0	0	1	1	17	2	17	21	82	16	6	21	15	1	0	0	0	0	200
	Susceptible host	0	0	0	0	4	0	15	13	63	29	22	34	15	3	0	2	0	0	200
Form 2	Optimum	0	0	0	0	9	0	12	15	68	16	12	29	31	3	1	4	0	0	200
	Reduced light	1	2	1	7	40	3	22	22	56	17	8	12	7	2	0	0	0	0	200
	Excessive humidity	0	0	0	0	0	0	2	4	41	20	20	41	49	10	2	4	0	7	200
	Deficient soil moisture	0	0	0	0	15	5	16	16	44	11	14	36	31	5	0	5	0	2	200

TABLE XIV

FREQUENCY DISTRIBUTION FOR WIDTHS OF UREDINIOSPORES OF PHYSIOLOGIC FORMS OF *P. graminis avenae* DEVELOPED UNDER VARIOUS ENVIRONMENTAL CONDITIONS AND ON DIFFERENT HOST PLANTS

Physiologic forms	Conditions	Frequency classes for spore width (in microns)												Total population
		11	12	13	14	15	16	17	18	19	20	21	22	
Form 1	Resistant host	0	0	0	0	8	17	72	44	21	21	7	10	200
	Susceptible host	0	0	29	28	52	48	38	5	0	0	0	0	200
Form 2	Optimum	0	0	43	29	46	36	43	3	0	0	0	0	200
	Reduced light	1	2	51	40	50	34	21	1	0	0	0	0	200
	Excessive humidity	0	0	10	22	34	42	66	15	5	2	2	2	200
	Deficient soil moisture	0	0	36	30	43	34	43	6	5	3	0	0	200

TABLE XV

INFLUENCE OF ENVIRONMENTAL CONDITIONS AND HOST PLANTS ON THE SIZE OF UREDINIOSPORES OF PHYSIOLOGIC FORMS OF *P. graminis avenae*

Physiologic form	Conditions	Constants for					
		Spore length			Spore width		
		Mean	Standard deviation	Coefficient of variability	Mean	Standard deviation	Coefficient of variability
Form 1	Congenial host	27.02 ± 0.11	2.43 ± 0.08	8.9 ± 0.30	15.26 ± 0.06	1.41 ± 0.05	9.2 ± 0.31
	Resistant host	26.08 ± 0.10	2.13 ± 0.07	8.2 ± 0.27	17.97 ± 0.05	1.64 ± 0.05	9.1 ± 0.31
Form 2	Optimum	27.12 ± 0.11	2.3 ± 0.08	8.5 ± 0.28	15.08 ± 0.07	1.45 ± 0.05	9.6 ± 0.32
	Reduced light	24.95 ± 0.12	2.54 ± 0.08	10.2 ± 0.34	14.60 ± 0.06	1.38 ± 0.05	9.4 ± 0.32
	Excessive humidity	28.64 ± 0.11	2.2 ± 0.07	7.6 ± 0.23	16.70 ± 0.08	1.69 ± 0.06	10.4 ± 0.35
	Deficient moisture	27.13 ± 0.13	2.74 ± 0.09	10.1 ± 0.34	15.40 ± 0.07	1.43 ± 0.05	9.3 ± 0.31

TABLE XVI

SUMMARY OF DIFFERENCES IN THE MEANS AND COEFFICIENTS OF VARIABILITY OF UREDINIOSPORES OF PHYSIOLOGIC FORMS OF *P. graminis avenae* DEVELOPED UNDER VARIOUS ENVIRONMENTAL CONDITIONS AND ON DIFFERENT HOST PLANTS

Physiologic form	Conditions compared	Arithmetical means				Coefficients of variability			
		Length		Width		Length		Width	
		Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.	Difference in means (in microns)	Difference divided by P.E.
Form 1	Congenial and resistant hosts..	0.94±.15	6.27	2.71±.08	33.88	0.7±.40	1.75	0.1±.44	0.23
	Optimum and reduced light...	2.17±.16	13.56	0.48±.09	5.33	1.7±.44	3.86	0.2±.45	0.44
	do excess humidity...	1.52±.16	9.50	1.62±.10	16.20	0.9±.36	2.50	0.8±.47	1.70
	do ... deficient moisture...	0.01±.17	0.06	0.32±.10	3.20	1.6±.44	3.64	0.3±.45	0.67
Form 2	Reduced light and excess humidity...	3.69±.16	23.06	1.62±.09	18.00	2.6±.41	6.34	1.0±.47	2.13
	do ... deficient moisture...	2.18±.18	12.11	0.80±.09	8.89	0.1±.48	0.02	0.1±.45	0.22
	Excess humidity and deficient moisture	1.51±.17	8.88	1.30±.10	1.30	2.5±.41	6.10	1.1±.47	2.34

In view of the fact that environmental conditions have been shown to influence spore size in *P. graminis* (31, 19), it seemed advisable to compare the above differences in spore size of the various forms with the differences induced in a single form by altered environmental conditions. Accordingly, the influence of an uncongenial host, of decreased light intensity, of excessive drouth, and of high humidity on the size of urediniospores of Form 2, was investigated. In each case, 200 spores were measured as before and the biometric constants of spore length and spore width were calculated. The results are presented in Tables XIII, XIV, XV, and XVI.

It will be noticed that altered environmental conditions resulted in changes in spore size as great as or even greater than the differences that existed between the spores of the different forms produced under identical conditions. Thus, reduced light intensity has a marked effect in reducing spore size and increasing variability. Excessive humidity, on the contrary, results in decreased variabilty and a larger spore. Drouth, in this particular case, seems to have induced a greater variability; and an uncongenial host reduced the spore size.

From all these results, it is evident that when all forms are grown under identical environmental conditions, a characteristic spore size does seem to predominate in any given physiologic form. The differences in size of spores between the various forms under such conditions, however, is less than the variation in the size of an individual form under varying environmental conditions. Consequently morphological differences, while they may serve still further to differentiate forms, can not be relied upon as an initial or sole means of identification.

OTHER DIFFERENCES BETWEEN THE FORMS

Forms 3 and 4 are very definitely characterized by the rapidity with which they form teliospores, as compared with the other forms. This is particularly marked with Form 4. In infections with Form 4, teliospores have been found to form within from 20 to 40 days following inoculation, depending on environmental conditions. With Form 3 the interval was usually but slightly longer; while it was very much longer with the other forms, when they formed teliospores at all. Under parallel conditions, teliospores consistently developed from 10 to 15 days earlier with Form 3 and 4 than with Forms 1 and 2. Since the teliospores also formed slightly sooner with Form 4 than with Form 3, there is the interesting suggestion that there is some correlation between the virulence of the form and the interval required to produce teliospores.

RELATION BETWEEN THE PATHOGENE AND THE HOST PLANT

The histological details of the infection of various wheat varieties by *Puccinia graminis* has been rather adequately worked out by

Stakman (28), Newton (23), Allen (1) and others. From their work it is evident that resistance in wheat varieties depends primarily on physiologic rather than on morphologic differences.[4] The delicate physiologic balance which determines resistance is specific against certain rust forms and is not necessarily maintained in the same way even toward very similar forms.

A parallel study of the infection of oats by *P. graminis avenae* seemed desirable. The problems presented in this connection, however, were so numerous that little more than a beginning could be made on them in an investigation of such wide scope as the present one.

The different types of hypersensitiveness, which are so varied, and in many respects different from those encountered in wheat stem rust infections, deserve special investigation.

The present work has been limited to a preliminary study of the infection on Victory as a type of thoroly susceptible host, and of Richland when attacked (1) by a form of rust to which it is susceptible and (2) by a form to which it is resistant.

The infection of a susceptible variety of oats, as typified by Victory, does not seem significantly different from the infection of a susceptible wheat variety. An appressorium forms over the stoma and from this a minute penetration tube passes through the stomatal opening. The contents of the appressorium flow through this tube and form a substomatal vesicle just under the stoma. From this substomatal vesicle, hyphae grow out in all directions among the adjoining cells. Haustoria are formed fairly abundantly, especially by the younger hyphae. Except where the infection is very heavy or where uredinia are being formed, there is very little killing of host tissue.

When Richland is infected by Form 4, to which it is completely susceptible, the process seems identical with that described for Victory. Illustrations of this type of infection are shown in Plate 7.

When Richland is inoculated with Form 2, to which it is markedly resistant, fewer germ tubes appear to enter the leaf than when it is inoculated with Form 4. This does not seem to be due to any mechanical difficulty in penetration, because a great many germ tubes do enter, and the penetration is quite normal. Indeed, in such cases the actual penetration tube may be small as compared with the stomatal opening. In many cases, however, the germ tubes wander aimlessly over the surface of the leaf or form appresoria which apparently never develop further. It seems rather that the rust fungus responds to some

[4] Since this manuscript was prepared, Hursh has published (42) the results of a cooperative investigation between the U. S. Department of Agriculture and the University of Minnesota in which he found that certain varieties of wheat are resistant to *P. graminis* on account of morphological peculiarities.

stimulus normally exerted by a congenial host and this stimulus is more or less specific to physiologic forms capable of infecting the particular host.

The hyphae that do enter behave very similarly to those described in the susceptible variety. The chief difference seems to be in the response of the host. Local killing is common and often very pronounced. The first indication of cell degeneration seems to be a slight plasmolysis. Then the chloroplasts and nucleus swell, the cell becomes very turgid, quickly disorganizes, and plasmolysis and complete degeneration follow. The process is gradual, however, and the fungus manages to produce small uredinia conspicuously lacking in vigor before its development is checked by the death of the host tissue. It is often surprising, tho, especially when environmental conditions are optimum and infection light, how far the development of the fungus may proceed before any indication of hypersensitiveness on the part of the host is evident. On the other hand, a marked hypersensitiveness rather frequently accompanies a very heavy infection on thoroly susceptible varieties like Victory. Much remains to be learned of the nature of resistance to oat rust and of the significance of hypersensitiveness in both resistant and susceptible varieties.

GRASS-HOST RANGE OF PHYSIOLOGIC FORMS

One of the most striking facts disclosed by a preliminary study of the epidemiology of oat stem rust in Western Canada is the apparent scarcity of grass hosts. *Dactylis glomerata* L., which is so commonly infected by *P. graminis avenae* wherever it occurs, has been introduced so sparingly in Western Canada that it is of slight importance in relation to oat rust.

During 1923 oat rust was collected only on *Avena sativa* L., *A. fatua* L., and *Hierochloe odorata* (L.) Wahlenb. A greenhouse investigation was undertaken to determine whether or not such a limited grass-host range represented the true condition in oat stem rust and whether the several physiologic forms differ markedly in their grass-host range.

About twenty species of grasses belonging to thirteen genera have been inoculated with the various physiologic forms. The results are presented in Table XVII. It will be noticed that the forms were very similar in their infection capabilities. The results may be summarized briefly as follows:

Hosts easily infected by artificial inoculation: *D. glomerata* L. and *Avena fatua* L.

Hosts weakly to moderately infected: *Agropyron caninum* (L.), Beauv.; *A. richardsonii* Schrad.; *Arrhenatherum elatius* (L.) Beauv.;

Bromus ciliatus L.; *Bromus purgans* L.; *Elymus curvatus* Piper. *Lolium perenne* L.; *Stipa viridula* Trin.

Hosts inoculated but not infected: *Andropogon scoparius* Mich.; *Agrostis verticillata* Vill.; *Agrostis retrofacta; Bromus inermis* Leyss.; *Elymus canadensis* L.; *Elymus virginicus* L.; *Hordeum jubatum* L.; and *Setaria glauca* (L.) Beauv.

Unfortunately, some of the more likely grass hosts were not available. Until these have been investigated, along with many others, it seems unwise to draw any sweeping conclusions. The results to date indicate, however, that the grass-host range of oat stem rust is rather limited.

It is extremely interesting to notice that the infection capabilities of the Swedish and South African forms parallel very closely those of our native forms. If physiologic forms arise through adaptation, as is sometimes postulated, the foreign forms might be expected to react differently from our native forms on our native grasses, but they did not.

In the light of the results obtained, it seems doubtful whether an extended investigation of the grass-host range of oat stem rust would be especially valuable. Thus, it will be noticed that one sample of *Dactylis glomerata* L. was uniformly resistant, while another sample was uniformly susceptible. That this variability in resistance is quite general in *Dactylis* was indicated by examination of this species in the grass plots at Manitoba Agricultural College. Moreover, it will be obvious from a study of Table XVII that this variability in resistance is not confined to *Dactylis glomerata*. Many cases are evident where a great variation in resistance occurred among the plants of a given species when infected by a single physiologic form. This variability is probably an expression of the heterozygosity of these, for the most part, open-pollinated plants. Therefore, it is unsafe to conclude that the resistance of a particular sample of grass worked with in the greenhouse represents the condition of that species as a whole. In general, the data secured by determining the form of rust present on naturally rusted grasses seem more significant and more desirable.

TABLE XVII

RESULTS OF INOCULATING GRASSES WITH *P. graminis avenae*, FORMS 1, 2, 3, 4, AND 5

Grass inoculated	Form 1		Form 2		Form 3		Form 4		Form 5	
	Results*	Character of infection	Results	Character of infection	Results	Character of infection	Results	Character of infection	Results	Character of infection
Agropyron caninum (L.) Beauv.	20	Weak	6	Weak	1	Weak; flecks sharply necrotic	15	Weak; flecks sharply necrotic	0	Flecks faint
	150;60		80;30		76;19		128;32		150;70	
Agropyron richardsonii Schrad.	0	Flecks sharply necrotic	35	Very weak	10	Very weak	5	Very weak	30	Very weak
	80;60		40		66;30		80;46		70;10	
Avena barbata Brot.	6	Vigorous	10	Vigorous	10	Vigorous	14	Vigorous	10	Vigorous
	7		10		10		14		12	
Andropogon scoparius Michx.	0	Flecks indistinct	0	Flecks minute; sharply necrotic	0	Flecks indistinct	0	Flecks indistinct	0	Flecks sharply necrotic
	60;50		114;110		96;80		82;68		115;98	
Andropogon furcatus Muhl.	0	Flecks indistinct	0	Flecks indistinct	0	Flecks indistinct	0	Flecks indistinct	0	Flecks indistinct
	50;42		58;34		69;42		86;41		75;50	
Agrostis verticillata Vill.	0	Flecks indistinct	0		0		0		0	
	46;18		62;12		50;0		57;0		66;0	
Agrostis retrofacta	0		0		0		0		0	
	24;0		32;0		40;0		27;0		43;0	
Arrhenatherum elatius (L.) Beauv.	8	Weak	26	Weak to moderate	13	Moderate to very weak	22	Moderate	27	Weak to moderate
	42;14		38		51;20		58		46	
Bromus inermis Leyss.	0	Flecks indistinct	0	Flecks discolored, sharply necrotic	0	Flecks indistinct	0		0	Flecks distinct; infection weak
	20;10		20;20		28;7		30;0		30;15	
Bromus ciliatus L.	40	Moderate	33	Weak to moderate	17	Moderate	18	Moderate	20	Flecks distinct; infection weak
	60		43;6		70;27		40		60;32	

TABLE XVII *Continued*

Grass inoculated	Form 1		Form 2		Form 3		Form 4		Form 5	
	Results	Character of infection	Results	Character of infection	Results	Character of infection	Results	Character of infection	Results	Character of infection
Bromus purgans L.	0	Flecks; discolored	96	Very weak; uredinia small; much hypersensitiveness	10	Very weak; much necrosis	0	Flecks necrotic and discolored	50	Weak
	96;70		105		160;140		150;138		130;40	
Dactylis glomerata L.	12	Weak	25	Weak	12	Weak	20	Weak	15	Weak
	12		28		18		22		15	
Dactylis glomerata L.	14	Vigorous	18	Vigorous	26	Vigorous	26	Vigorous	32	Vigorous
	20		10		40		45		36	
Elymus canadensis L.	0	Flecks minute and necrotic	1	Flecks minute, distinct, necrotic.	0	Flecks faint to sharply necrotic	0	Flecks numerous; sharply necrotic	0	Flecks minute; sharply necrotic
	70;52		88;86	One plant susceptible	92;92		101;98		75;60	
Elymus curvatus Piper.	20	Weak; flecks faintly to sharply necrotic	44	Variable, weak to moderate; flecks indistinct	31	Weak; flecks faint to sharply necrotic; uredinia small	58	Variable; weak to moderate; flecks faint to sharply necrotic	0	Flecks distinct
	66;40		134;20		122;52		33;41		80;61	
Elymus virginicus L.	0	Flecks distinct	0		4	Weak; uredinia very small; hypersensitiveness very pronounced	0	Flecks indistinct	0	Flecks indistinct
	50;38		46;0		41;5		20;5		40;10	
Hordeum jubatum L.	0		0		0		0		0	
	14;0		24;0		18;0		32;0		28;0	
Lolium perenne L.	0	Flecks distinct	0	Flecks distinct	0	Flecks distinct	0	Flecks indistinct	0	Flecks indistinct
	68;42		45;23		76;45		26;20		31;15	
Setaria glauca (L.) Beauv.	0		0	Flecks indistinct	0		0		0	Flecks indistinct
	60;0		50;6		66;0		70;0		60;10	
Stipa viridula Trin.	0	Flecks distinct	0	Flecks sharply necrotic	80	Weak; uredinia small; hypersensitiveness present	0	Flecks sharply necrotic	0	Sharply necrotic
	50;38		55;48		98;10		83;70		60;60	

* Numerator number of plants infected; denominator total number inoculated. Figures following semicolon (;) indicate number of plants flecked.

FIELD TESTS OF OAT VARIETIES

The reaction of a large number of oat varieties to stem rust under field conditions was tested at Winnipeg and Brandon, Manitoba, and at Indian Head, Saskatchewan. It was hoped that additional differential hosts might thus be discovered. Also, since the varieties White Tartar and Richland were included in each test, the experiment served as an additional test of the occurrence of Forms 3 and 4.

At Winnipeg, one rod row of each of eighty-five varieties was grown. Twenty-five of these varieties were grown at Brandon and at Indian Head. In each case, varieties belonging to the six species of *Avena—A. nuda, A. brevis, A. strigosa, A. sterilis, A. sativa,* and *A. orientalis*—were included in the test. The varieties grown at the three places, together with the percentage of infection which developed in each case are included in Table XVIII.

TABLE XVIII

FIELD TESTS OF VARIETAL RESISTANCE OF OATS TO STEM RUST

Variety	Classification	Severity of infection (per cent)					
		Winnipeg, Man.		Brandon, Man.		Indian Head, Sask.	
		Main crop	Late growth	Main crop	Late growth	Main crop	Late growth
Avena nuda	*A. nuda*	60	..	60	..	5	60
Avena strigosa	*A. strigosa*	45	..	60-75	..	5	40
Avena brevis	*A. brevis*	50	..	75-80	..	20	50
Avena sterilis nigra	*A. sterilis*	50	80	..	..	5	50
Avena sterilis (selection)	do	65	80	80-90	..	90	..
Red Rustproof	do	80	95	90-95	..	85	..
Burt	do	35	90	10	90	10	90
King	do	50-90	95	85-95	..	95	..
Okl. 606	do	80	95	80-95	..	10	75
Winterturf	*A. sativa*	90	..	..	..	..	..
Culbertson	do	85	..	..	..	..	..
Black Norway	do	75	90	..	..	..	..
Victor	do	45	90	..	..	..	..
Monarch, C.I. 1876	do	35	95	40	90	5	75
Black Mesdag, C.I. 1877	do	30	90	..	..	tr	..
Black Diamond	do	40	95	..	..	..	..
Monarch Diamond	do	50	95	..	..	..	..
Variety 703	do	30-80	..	..	..	..	..
Joanette, Minn. 550	do	40	95	50	90	..	..
C.I. 620	do	45	95	..	..	..	..
Danish Island	do	30	95	..	..	..	..
Early Gothland, C.I. 1723	do	15	95	..	..	..	..
Belyak, C.I. 1630	do	15	95	..	..	..	..
Silvermine, Minn. 506	do	20	90	..	..	..	..
Scottish Chief	do	10	85	..	..	..	..
June	do	50	95	..	..	..	..
Swedish Select, C.I. 802	do	20	95	..	..	..	..
Lincoln, C.I. 1463	do	40	90	..	..	..	..
Garton 748	*A. orientalis*	25	95	20	95	tr	70
Garton 784	do	20	90	10-15	90	15	80
Garton Grey	do	50	95	40	95	20	85
Black Tartarian	do	50	95	80	95	20	60
Golden Giant, C.I. 1606	do	45	70	70	95	10	70
Sparrowbill, C.I. 1604	do	55	90	80	95	30	65

TABLE XVIII—*Continued*

Variety	Classification	Severity of infection (per cent)					
		Winnipeg, Man.		Brandon, Man.		Indian Head, Sask.	
		Main crop	Late growth	Main crop	Late growth	Main crop	Late growth
Garton 585	*A. orientalis*	60	90	..	..	..	..
Tartar King	do	5	95	60	95	10	65
Storm King, C.I. 1602	do	15	90	80	90	5	75
White Tartar	do	5	5	..	..	..	..
Green Mountain	do	3	3	..	..	..	..
White Tartar, C.I. 1614	do	3	3	..	..	..	..
North Finnish, C.I. 1882	*A. sativa*	50	95	..	..	5	60
Gar. 473	do	50	95	..	..	..	..
Gar. 691	do	75	95	..	..	..	..
Kherson	do	50	98	tr	90	tr	..
Kherson selection	do	55	98	5	95	tr	..
60-Day, C.I. 826	do	55	98	10	90	tr	..
60-Day selection	do	5	90	5	90	..	..
Early Champion, C.I. 1623	do	tr	95	..	..	..	..
Awnless Probsteier	do	30	95	..	..	..	..
Japan selection	do	40	95	..	..	..	..
Golden Drop	do	10	95	..	..	..	..
C.I. 603	do	35	95	..	..	..	..
Green Russian, Iowa 96	do	40	95	..	..	..	..
Canadian, C.I. 1625	do	35	95	..	..	..	..
Tobolsk, C.I. 1709	do	50	95	..	..	..	..
Silvermine selection	do	55	95	..	..	..	..
C.I. 602	do	40	95	..	..	..	..
Early Dakota	do	35	95	..	..	..	..
Irish Victor, C.I. 1896	do	20	95	..	..	..	..
White Tartar, Minn. 539	do	3	3	tr	tr	tr	20(2)
Albion, C.I. 729	do	10	95	..	..	..	..
Early Mt., C.I. 1624	do	80	..	..	..	..	..
Standwell, C.I. 1975	do	75	80	..	..	..	..
Empire, C.I. 1974	do	50	90	..	..	..	..
Old Island Black, C.I. 1881	do	65	95	..	..	..	..
Idamine, C.I. 1834	do	65	90	..	..	..	..
Black American, C.I. 1758	do	50	95	..	..	..	..
Wisconsin No. 7, C.I. 1154	do	40	90	..	..	..	..
Iowar, C.I. 847	do	30	90	..	..	..	..
Richland, Iowa 105	do	3	3	tr	tr	tr	tr
Nebraskas, No. 21, C.I. 841	do	10	90	..	..	..	..
Cornwall, C.I. 1317	do	65	95	..	..	..	..
Kanata, C.I. 839	do	75	95	..	..	..	..
Ferguson Navarra, C.I. 966	do	60	90	..	..	..	..
C.I. 749	do	35	80	..	..	..	..
C.I. 836	do	30	75	..	..	..	..
Red Rustproof, C.I. 1356	*A. sterilis*	90	95	..	..	..	..
Golden Rain, C.I. 1718	*A. sativa*	35	90	..	..	..	..
Cole, C.I. 843	do	3	90	..	..	..	..
Cornellian, C.I. 1843	do	10	95	..	..	..	..
Richland, C.I. 787	do	3	3	..	..	..	..
Aurora	do	90	..	..	..	..	..
Red Texan	do	90	..	..	..	..	..
Richland, K.S. 209	do	5	3	..	..	..	..
Banner	do	40	95	90	85	..	..

From a study of this table it is evident that, while some varieties matured early enough to escape heavy infection, few possessed any resistance. Indeed, resistance seemed entirely lacking except where it was already known to be present, i.e., in the differential varieties White Tartar, Richland, and Strain 703. In Strain 703, occasional plants were found quite evidently infected by Form 1 as well as by a form to which they were susceptible. In such cases, the weaker form was very largely obscured.

The fact that White Tartar and Richland were consistently resistant at all three places is extremely interesting. It is to be hoped that further investigation will support this indication of the absence in America of Forms 3 and 4, which are so virulent. The resistance of these varieties in the field tests, together with the fact that they were resistant to all native collections of oat rust from either the United States or Canada, is certainly an indication that Forms 3 and 4 are rare if they occur at all in this country. Since a limited distribution is difficult to reconcile with the virulence and extended host range of these forms, it seems more probable that they do not occur at all in America. If this can be established with reasonable certainty, it will simplify the problem to the extent at least that varieties with resistance adequate to withstand all our indigenous forms will be available.

GEOGRAPHICAL DISTRIBUTION

The sources of 65 collections made during 1921, 1922, and 1923 are given in Table XIX. For the sake of completeness, 23 forms already reported on by Stakman, Levine, and Bailey, (33) are included.

Form 1 is common in occurrence and is widely distributed. It has been collected from Saskatchewan to Mexico.

Form 2 seems even more abundantly distributed than Form 1 in the central and northern parts of North America, extending to about 500 miles north of Winnipeg, in Maine and Mexico, as well as in South Africa and Sweden.

Forms 3 and 4 have not been found in North America. In view of the number of collections made and the very wide territory covered by them, it seems that these forms must be very limited in distribution, if they occur at all in this region.

Form 5, while of somewhat less frequent occurrence than Forms 1 and 2, seems also widespread.

TABLE XIX

DISTRIBUTION OF PHYSIOLOGIC FORMS OF STEM RUST OF OATS

Physiologic form	Place of collection	Collector	Original host
P. graminis avenae, Form 1	Zelma, Sask.	W. P. Fraser	*Avena sativa*
	Litchfield, Minn.	L. W. Melander	do
	Rosetown, Minn.	M. N. Levine	do
	Lafayette, Ind.	W. Butler	do
	St. Paul, Minn.	F. Griffee	do
	Boerne, Tex.	W. Butler	do
	San Antonio, Tex.	W. Butler	do
	Robards, Tex.	W. Butler	do
	Huntley, Ill.	J. L. Seal	do
	Cartwright, Man.	I. L. Conners	do
	Carlyle, Sask.	P. M. Simmonds	do
	Dauphin, Man.	D. L. Bailey	do
	Piedras Negras, Mex.	E. C. Stakman	do
	Neepawa, Man.	R. C. Russell	do
P. graminis avenae, Form 2	Saskatoon, Sask.	W. P. Fraser	do
	Zelma, Sask.	W. P. Fraser	do
	Presque Isle, Me.	F. Weiss	do
	Litchfield, Minn.	L. W. Melander	do
	Rosetown, Minn.	M. N. Levine	do
	Redfield, S. D.	M. N. Levine	do
	Huron, S. D.	M. Lapidus	do
	Lafayette, Ind.	W. Butler	do
	Chillicothe, Mo.	W. Butler	do
	Norman, Okla.	W. Butler	*Dactylis glomerata*
	Lawton, Okla.	H. Ostrom	*Avena sativa*
	San Marcos, Tex.	W. Butler	do
	Robards, Tex.	W. Butler	do
	Saltillo, Mex.	E. C. Stakman	do
	Potchefstroom, S. Africa	G. F. Puttick	do
	Brockway, Mich.	E. B. Lambert	do
	Berens River, Man.	G. R. Bisby	do
	Carman, Man.	R. C. Russell	do
	Dauphin, Man.	F. J. Greaney	do
	Dauphin, Man.	D. L. Bailey	*Avena fatua*
	Carlyle, Sask.	P. M. Simmonds	*Avena sativa*
	Edmonton, Alta.	W. P. Fraser	do
	Grandview, Man.	R. C. Russell	do
	Hendrum, Minn.	J. J. Christensen	do
	Letellier, Man.	D. L. Bailey	*Avena fatua*
	Lashburn, Sask.	W. P. Fraser	*Avena sativa*
	Morris, Man.	D. L. Bailey	do
	Melfort, Sask.	W. P. Fraser	do
	Litchfield, Minn.	L. W. Melander	do
	Moose Jaw, Sask.	W. P. Fraser	do
	Norway House, Man.	G. R. Bisby	do
	Neepawa, Man.	R. C. Russell	do
	Roblin, Man.	R. C. Russell	do
	Saltcoats, Sask.	W. P. Fraser	do
	Stonewall, Man.	R. C. Russell	do
	Indian Head, Sask.	D. L. Bailey	do
	Neepawa, Man.	R. C. Russell	do
	Morris, Man.	D. L. Bailey	*Avena fatua*
P. graminis avenae, Form 3	Upsala, Sweden	E. C. Stakman	*Avena sativa*
	Potchefstroom, S. Africa	G. F. Puttick	do
P. graminis avenae, Form 4	Upsala, Sweden	E. C. Stakman	do

TABLE XIX—*Continued*

Physiologic form	Place of collection	Collector	Original host
P. graminis avenae,	Zelma, Sask.	W. P. Fraser	*Avena sativa*
Form 5	Rosthern, Sask.	W. P. Fraser	*Torresia odorata*
	Swan River, Man.	D. L. Bailey	*Avena sativa*
	St. Jean, Man.	D. L. Bailey	*Avena fatua*
	Roblin, Man.	R. C. Russell	*Avena sativa*
	Minnetonas, Man.	F. J. Greaney	do
	Morden, Man.	R. C. Russell	do
	Erickson, Man.	F. J. Greaney	do
	Gretna, Man.	D. L. Bailey	*Avena fatua*
	Brandon, Man.	I. L. Conners	*Avena sativa*
	Assiniboia, Sask.	W. P. Fraser	do
	Carman, Man.	R. C. Russell	do
	Snake Island, Man.	G. R. Bisby	do
	Swift Current, Sask.	W. P. Fraser	do
	Carlyle, Sask.	P. M. Simmonds	do

DISCUSSION AND CONCLUSION

The comparatively slight degree of specialization which appears to exist in *P. graminis avenae* will be striking to any one familiar with the marked degree of specialization which has been shown to exist in *P. graminis tritici* (32). Why this apparently slight degree of specialization should be the case is an interesting subject for speculation. The fact that five physiologic forms have been distinguished suggests that there may be still more. This idea is further supported by the rather marked variability in the reaction of White Tartar and perhaps also by the heterogeneous infection on the Joanette Strain. Moreover, a fairly close approximation of the total number of physiologic forms which could be isolated with the number of differential hosts available has been reached. This is more evident when it is remembered that Joanette Strain and Strain 703 react virtually identically and that Monarch Strain, Richland, and Heigira Strain also react as a single group with apparently identical resistance. If a degree of specialization approximating that of *P. graminis tritici* be assumed, some difference must exist in the origin or nature of oat varieties as compared with wheat varieties. Only in this way could the lack of differential hosts necessary to isolate more physiologic forms of oat rust be explained. Such a difference is not immediately apparent. A comparison of the chromosome number in wheat and oat species is interesting. In wheat we have the haploid numbers 7, 14, and 21 in the Einkorn, Emmer, and Spelt groups, respectively. In oats (27), the species *Avena brevis, A. barbata,* and *A. strigosa* have 7 or 14 chromosomes as compared with 21 for *A. sativa.* From this it is evident that an equal range in chromosome number provides an equal chance for as great variability in oat varieties as in wheat. If such a variability is lacking in oat varieties, therefore, the only explanation presenting itself, in addition to the recognized fact

that natural crossing occurs more rarely in oats, seems to be that mutations are also rare in oats as compared with wheat.

From a practical standpoint, these investigations give us still further cause for believing that the resistance of such varieties as White Tartar and Richland will be adequate to withstand the attack of all our native physiologic forms. If such be the case, the oat stem rust problem may be regarded as well on the way to solution, through the work of Parker (24, 25), Garber (10), Griffee (11), and others. As a safeguard against the occurrence or possible introduction of such virulent forms as 3 and 4, the search for a variety uniformly resistant to all the physiologic forms of *P. graminis avenae* should be continued.

SUMMARY

1. Five physiologic forms of *Puccinia graminis avenae* have been distinguished, and the characteristic reaction of each on several differential hosts is described.

2. In addition to differences in parasitism, significant differences in the size of the urediniospores were found between some of the physiologic forms when all were grown under identical conditions. In such cases, however, the differences were less than the fluctuations induced in a single form by varying the environmental conditions. Therefore morphologic differences alone could not be relied upon as a means of identifying the individual forms.

3. A preliminary study of the grass-host range of the five physiologic forms is reported on. The infection capabilities of the five forms are remarkably similar and the host range seems to be decidedly limited.

4. The geographic distribution of 14 cultures of Form 1, 38 cultures of Form 2, 15 cultures of Form 5, two cultures of Form 3, and one of Form 4 is given. Form 4 is of Swedish origin and has not been found in North America. Two cultures of Form 3, one from Sweden and one from South Africa, have been studied, but none of American origin has been found. Forms 1, 2, and 5 are very widely distributed throughout the United States and Canada.

5. Field tests of a large number of oat varieties were made at Indian Head, Saskatchewan, and at Brandon and Winnipeg, Manitoba. The uniform susceptibility of all the varieties except White Tartar and Richland, indicated the possible presence in these localities of Forms 1, 2, and 5 and the definite absence of Forms 3 and 4.

6. The infection of Victory, which is susceptible to all five physiologic forms, proceeds in a manner similar to that of wheat varieties susceptible to *P. graminis tritici*. Penetration is stomatal, an appressorium forms over the stoma, a very small penetration tube passes through the stomatal opening, and the contents of the appressorium

flow through and form a substomatal vesicle beneath. There is very little killing of host tissue except where uredinia are formed.

7. The resistance of Richland seems not at all dependent on morphologic characters. The mode of infection is much the same as in a susceptible variety except that pronounced local killing of the infected tissue seems to limit the development of the fungus.

LITERATURE CITED

1. Allen, Ruth F. A cytological study of infection of Baart and Kanred wheats by *Puccinia graminis tritici.* Jour. Agr. Res. **23**:131-151. 1923.
2. Carleton, M. A. Cereal rusts of the United States. U. S. Dept. Agr., Div. Veg. Physiol. and Path. Bul. 16. 1899.
3. ————. Investigation of rusts. U. S. Dept. Agr., B.P.I. Bul. 63. 1904.
4. Eriksson, Jacob. Über die Specialisirung des Parasitismus bei den Getreiderostpilzen. Ber. Deutsch. Bot. Gesell. **12**:292-331. 1894.
5. Ist die verschiedene Widerstandfahigkeit der Weizensorten gegen Rost konstant oder nicht? Zeit. Pflanzenk. **5**:198-200. 1895.
6. ———— and Henning, Ernst. Die Getreideroste, VII. 464 p. Stockholm. 1896.
7. Fraser, W. P. Strains of stem rust in wheat; preliminary report. Dom. Can. Dept. of Agr., Div. Botany Interim Report for year ending March 31, 1922, pp. 64-65. 1922.
8. ———— and Bailey, D. L. Biologic forms of wheat stem rust in western Canada. Phytopath. **11**:202. 1921.
9. Freeman, E. M. and Johnson, E. C. The rusts of grains in the United States. U. S. Dept. Agr., B.P.I. Bul 216. 1911.
10. Garber, R. J. Inheritance and yield with particular reference to rust resistance and panicle type of oats. Minn. Agr. Exp. Sta. Tech. Bul. 7, pp. 1-62. 1922.
11. Griffee, Fred. Breeding oats resistant to stem rust. Jour. Hered. **13**:187-190, 3 fig. 1922.
12. Hitchcock, A. S. and Carleton, M. A. Second report on rust of grain. Kan. Agr. Exp. Sta. Bul. 46. 1894.
13. Hoerner, G. R. Biologic forms of *Puccinia coronata* on oats. Phytopath. **9**:309-314. 1919.
14. ————. Infection capabilities of crown rust of oats. Phytopath. **12**:4-15. 1922.
15. Hungerford, Charles W. and Owens, C. K. Specialized varieties of *Puccinia glumarum* and hosts for variety *tritici.* Jour. Agr. Res. **25**:363-401. 1923.
16. Jaczewski, A. von. Studien über das Verhalten das Schwarzrostes des Getreides in Russland. Zeit. Pflanzenk. **20**:321-359. 1910.
17. Johnson, E. C. Timothy rust in the United States. U. S. Dept. Agr., B.P.I. Bul. 224, pp. 1-22. 1911.
18. Leach, Julian G. The parasitism of *Puccinia graminis tritici* Erikss. and Henn. and *P. graminis tritici-compacti,* Stak. and Piem. Phytopath. **9**: 59-88. 1919.
19. Levine, M. N. A statistical study of the comparative morphology of biologic forms of *Puccinia graminis.* Jour. Agr. Res. **24**:539-567. 1923.
20. ———— and Stakman, E. C. A third biologic form of *Puccinia graminis* on wheat. Jour. Agr. Res. **13**:651-654. 1918.

1. ————. Biologic specialization of *Puccinia graminis secalis*. Phytopath. 13:35. 1923.
2. Mains, E. B. and Jackson, H. S. Two strains of *Puccinia triticina* on wheat in the United States. Phytopath. 11:40. 1921.
3. Newton, Margaret. Studies in wheat stem rust (*Puccinia graminis tritici*). Trans. Royal Soc. Can. 3rd series. 16:153-210. 1922.
4. Parker, John H. Greenhouse experiments on the rust resistance of oat varieties. U. S. Dept. Agr. Bul. 629, pp. 1-16. 1918.
5. ————. A preliminary study of the inheritance of rust resistance in oats. Jour. Amer. Soc. Agron. 12:23-38. 1920.
6. Reed, George M. Physiological specialization of parasitic fungi. Brooklyn Botanic Garden Memoirs 1:348-409. 1918.
7. Sax, Karl. The relation between chromosome number, morphological characters, and rust resistance in segregates of partially sterile wheat hybrids. Genetics 8:301-321. 1923.
8. Stakman, E. C. A study in cereal rusts: Physiological races. Minn. Agr. Exp. Sta. Bul. 138. 1914. (Out of print.)
9. ————. Relation between *Puccinia graminis* and plants highly resistant to its attack. Jour. Agr. Res. 4:193-200. 1915.
10. ———— and Hoerner, G. R. The occurrence of *Puccinia graminis tritici-compacti* in the southern United States. Phytopath. 8:141-149. 1918.
11. ———— and Levine, M. N. Effect of certain ecological factors on the morphology of the urediniospores of *Puccinia graminis*. Jour. Agr. Res. 16:43-77. 1919.
12. ————. The determination of biologic forms of *Puccinia graminis* on *Triticum spp.* Univ. of Minn. Agr. Exp. Sta. Tech. Bul. 8, pp. 1-10. 1922.
13. ———— and Bailey, D. L. Biologic forms of *Puccinia graminis* on varieties of *Avena spp.* Jour. Agr. Res. 24:1013-1018. 1923.
14. ———— and Leach, J. G. New biologic forms of *Puccinia graminis*. Jour. Agr. Res. 16:103-105. 1919.
15. ————, Parker, John H., and Piemeisel, F. J. Can biologic forms of stem rust of wheat change rapidly enough to interfere with breeding for rust resistance? Jour. Agr. Res. 14:111-123. 1918.
16. ———— and Piemeisel, F. J. A new strain of *Puccinia graminis*. Phytopath. 1:73. 1917.
17. ————. Biologic forms of *Puccinia graminis* on cereals and grasses. Jour. Agr. Res. 10:429-495. 1917.
18. ———— and Levine, M. N. Plasticity of biologic forms of *Puccinia graminis*. Jour. Agr. Res. 15:221-250. 1918.
19. Vavilov, N. I. Materially k voprosu ob ustoychivosti khlevnykh zlakov protiv parasiticheskikh grybov. Trudy Selec. Sta. Moscow, Agr. Inst. 1: 1-110. 1913.
20. Ward, H. M. The bromes and their rust fungus, *Puccinia dispersa* Erikss. Ann. Bot. 15:560. 1901.
21. ————. On the relations between host and parasite in the bromes and their brown rust, *Puccinia dispersa* Erikss. Ann. Bot. 16:233-315. 1902.
22. Hursh, C. R. Morphological and physiological studies on the resistance of wheat to *Puccinia graminis tritici* Erikss. and Henn. Jour. Agr. Res. 27: 381-411. 1924.

EXPLANATION OF PLATES

Plate 1.

Classes of host reaction: Resistant (R), susceptible (S), and indeterminate (I), as indicated by different types of infection (0, 1, 2, 3, 4, and X) produced by physiologic forms of *Puccinia graminis avenae* on different varieties of oats.

Class R. (Resistant), including 3 subclasses corresponding to infection types 0, 1, and 2.

a. Practically immune (Infection type 0). No uredinia are developed, but sharply defined hypersensitive flecks are usually present.

b. Extremely resistant (Infection type 1). Infection very light; uredinia minute and scattered and surrounded by very sharply defined necrotic areas.

c. Moderately resistant (Infection type 2). Infection light; uredinia usually small and scattered; hypersensitive areas varying from sharply defined necrosis to pronounced chlorosis.

Class S (Susceptible), including two subclasses, corresponding to infection types 3 and 4.

d. Moderately susceptible (Infection type 3). Infection moderate; uredinia midsized with a tendency to coalesce; true hypersensitiveness absent, but light chlorotic areas usually present.

e. Completely susceptible (Infection type 4). Infection normal and heavy; uredinia large, numerous, and confluent; hypersensitiveness entirely absent, but chlorosis may be present when cultural conditions are unfavorable.

Class I (Indeterminate), representing the heterogeneous (X) type of infection.

f. Heterogeneous reaction (Infection type X). Uredinia very variable, apparently including all types and quantities of infection, often on the same blade; no mechanical separation seems to be possible as, on reinoculation, spores from small uredinia may produce large ones, and vice versa. In general, the infection is ill-defined.

Plate 2.

Puccinia graminis avenae (Form 1). Two leaves each of (1) Joanette Strain, (2) Monarch Strain, (3) Strain 703, (4) White Tartar, (5) Richland, (6) Heigira Strain, and (7) Victory.

Plate 3.

Puccinia graminis avenae (Form 2). Two leaves each of (1) Joanette Strain, (2) Monarch Strain, (3) Strain 703, (4) White Tartar, (5) Richland, (6) Heigira Strain, and (7) Victory.

Plate 4.

Puccinia graminis avenae (Form 3). Two leaves each of (1) Joanette Strain, (2) Monarch Strain, (3) Strain 703, (4) White Tartar, (5) Richland, (6) Heigira Strain, and (7) Victory.

Plate 5.

Puccinia graminis avenae (Form 4). Two leaves each of (1) Joanette Strain, (2) Monarch Strain, (3) Strain 703, (4) White Tartar, (5) Richland, (6) Heigira Strain, and (7) Victory.

Plate 6.

Puccinia graminis avenae (Form 5). Two leaves each of (1) Joanette Strain, (2) Monarch Strain, (3) Strain 703, (4) White Tartar, (5) Richland, (6) Heigira Strain, and (7) Victory.

Plate 7.

A. Appressorium developed on Richland from an inoculation with *Puccinia graminis avenae,* Form 2.

B. Entrance of penetration tube in Richland inoculated with Form 2.

C. Inner view of a stoma of Victory, 102 hours after inoculation with uredinio-spores of Form 2. Hyphae developed from substomatal vesicle.

D. Cross-section of Richland showing method of entrance of Form 4.

E. Appressoria developing over stomata on Victory inoculated with Form 2.

PLATE I



a b c



d e f

PLATE 2



1 2 3 4 5 6 7

PLATE 3



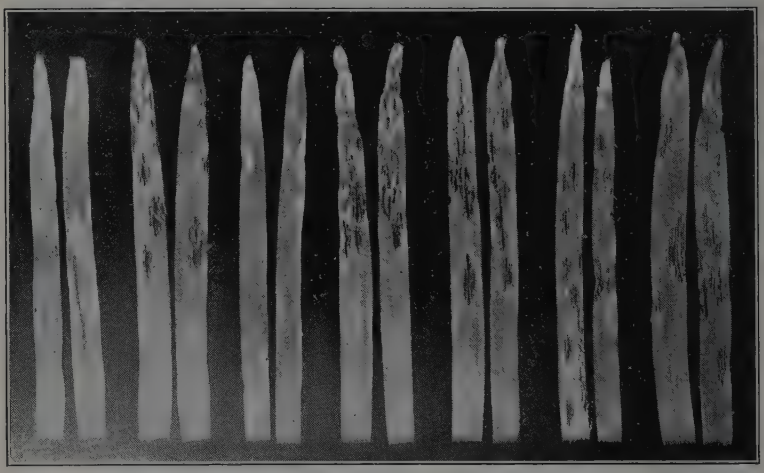
1 2 3 4 5 6 7

PLATE 4



1 2 3 4 5 6 7

PLATE 5



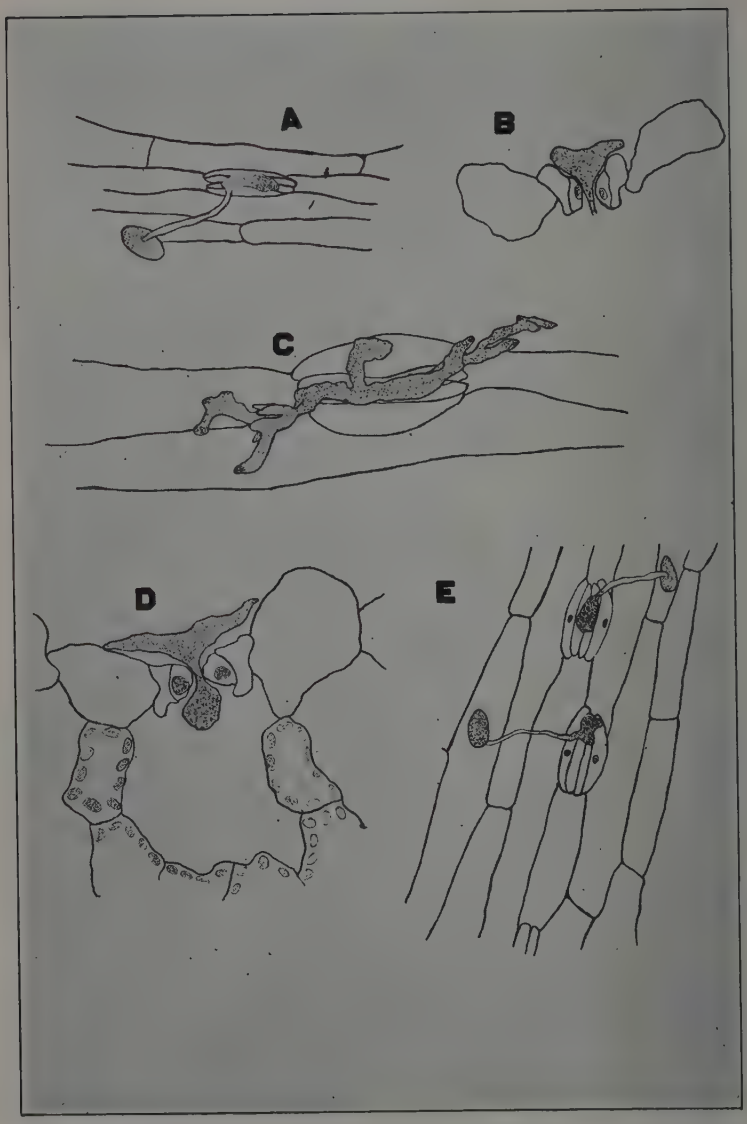
1 2 3 4 5 6 7

PLATE 6



1 2 3 4 5 6 7

PLATE 7



ECHNICAL BULLETIN 36 MARCH 1926

University of Minnesota
Agricultural Experiment Station

IN CO-OPERATION WITH

UNITED STATES DEPARTMENT OF AGRICULTURE,
BUREAU OF PLANT INDUSTRY

Flax Rust and its Control

A. W. Henry
Division of Plant Pathology and Botany

UNIVERSITY FARM, ST. PAUL

FLAX RUST AND ITS CONTROL[1]

By A. W. Henry

INTRODUCTION

The rust of cultivated flax, *Linum usitatissimum* L., is virtually coextensive with the flax crop. It occurs in the seed-flax regions of Argentina, North America, India, and Russia; and the fiber-flax centers, most of which are in the eastern hemisphere. The disease is perhaps most commonly known simply as flax rust, but in Argentina it is called "polvillo" (dust) (15). In Ireland the term "rust" is applied to the uredinial stage while the telial stage is called "firing" (23), and in Friesland "zwartstip" (30).

In North America, rust has been reported on cultivated flax from nine states of the United States and from five provinces of Canada (33, 34, 35). Most of the North American crop is seed flax, grown chiefly for linseed oil, altho a small part of the straw is utilized for insulating, upholstering materials, and the like. A relatively small acreage of fiber flax is grown in eastern Canada and in two centers in the United States, one in eastern Michigan, and the other in the Willamette Valley of Oregon (21). Fish nets, twine, thread, mats, toweling, insulating and upholstering tow are the chief products. The seed is saved from much of the crop, and profits from its sale form an important part of the returns (9, 20, 21). Altho flax rust has recently been found in both of the fiber-flax districts of the United States, destructive epidemics apparently have not occurred. Every effort should be made to prevent the disease from spreading and becoming destructive.

DAMAGE FROM FLAX RUST

The chief injury to seed flax due to rust is a reduction in the yield of seed. This results from defoliation and from the fact that the fungus on the stem and other parts uses food materials which otherwise would go to form seeds. Flax plants usually are not killed by rust under field conditions, altho late-maturing plants of very susceptible varieties may be killed. In the greenhouse, seedling plants are frequently killed when artificially inoculated (Plate I, E and F). In

[1] Co-operative investigations between the University of Minnesota Agricultural Experiment Station and the Offices of Cereal Investigations and Fiber Plant Investigations of the United States Department of Agriculture.

the field, flax is usually beyond this stage before rust becomes sufficiently abundant to be destructive. The disease is apparently rather destructive in India; in fact, almost as important as black stem rust of wheat, reductions in yield of flax seed of 28 per cent of the crop having been reported there (8).

The average annual loss of seed flax from rust in North Dakota in 1923 was approximately 1 per cent (34). In 1924 rust was more abundant and the losses were heavier in both North Dakota and Minnesota than in 1923 (36). Estimated losses were reported in some fields as high as 10 per cent of the crop. Flax rust again did considerable damage in certain fields in 1925.

Rust may lower the yield of seed of fiber flax also, but the chief injury results from the direct effect of the fungus on the stems. It is naturally most destructive to flax grown for linen and other products requiring high quality fiber. Pethybridge and Lafferty (23) state that "'firing' not only spoils the appearance of the flax straw but renders it liable to break at the attacked spots, and affects the fibers in some cases. Moreover the black fungus tissue does not disappear during retting, and some of it at least remains adhering to the fibers even after scutching and hackling have been carried out." And Tobler (29), summarizing the effect of the disease on fiber flax, says: "from an industrial point of view flax rust does not only damage the fibers in the stems infected but it may even dissolve them. Moreover it prevents the decaying, thus causing 'measly' fibers. Stems of flax severely infected with rust fungi are useless and should be removed."

THE PATHOGENE

The flax rust fungus was first described in 1801 by Persoon (28), who called it *Uredo miniata* var. *Lini* Pers. It was transferred by Léveillé (19), in 1847, to the genus *Melampsora* and is now perhaps most commonly known as *Melampsora lini* (Pers.) Lév., altho, according to Arthur's classification (4), it is called *Uredo lini* Schum. Körnicke (31), in 1865, proposed a new variety, *M. lini* var. *liniperda*, for the rust on *L. usitatissimum*, since his observations indicated that this rust was distinct physiologically from that on *Linum catharticum*. Fuckel (13), in 1869, distinguished the rust on *L. usitatissimum* from that on *L. catharticum* on the basis of spore size, and called the former *M. lini* var. *major* and the latter *M. lini* var. *minor*. Palm (22), in 1910, made repeated unsuccessful attempts to infect *L. usitatissimum* with urediniospores from *L. catharticum* and also noted that the teliospores of the rust on cultivated flax were larger than those on *L. catharticum*. He therefore considered that the rust on *L. usitatissimum*

was an independent species and called it *M. liniperda* (Körnicke) Palm. According to present ideas on the classification of the fungi (32), it is probable that the rust of cultivated flax would be regarded as a variety of *M. lini* rather than a new species, and on this basis Körnicke's name might well be retained.

Altho numerous wild species of *Linum* (4, 14, 28) are attacked by rust, it has been shown that there are sharp differences in the infection capabilities of several of these rusts (7, 22, 28). Some of them are apparently incapable of attacking cultivated flax. In the United States, rust has been reported on several wild species. Anderson (2), in 1889, reported that rust "was ruinous to *L. rigidum* in some seasons in Montana and sharply attacked *L. lewisii.*" Galloway (14) in the same year pointed out that it had also been found on *L. virginicum* (in Iowa), *L. perenne* (in Montana, Arizona, and Nevada), and on *L. sulcatum* (in Iowa). Both refer to the possibility of the pathogene spreading to cultivated flax, but Galloway states that it had not been found on cultivated flax in the United States to his knowledge up to that time. Arthur (4) lists three additional species —*L. breweri* A. Gray, *L. congestum* A. Gray, and *L. drymarioides* Curran—as hosts of *M. lini* in California.

While it is known that the rust of cultivated flax can perpetuate itself readily in the absence of any wild species of *Linum*, it is possible that some of them may serve to increase the inoculum. Altho no reports of successful infection of cultivated flax with rusts from wild species have come to the writer's attention, it is quite possible that some of them can infect cultivated flax. A few cases of successful infection of wild species with rust from cultivated flax have been reported. Arthur (3) obtained successful infection of *L. lewisii* with telial material from cultivated flax; Pethybridge *et al.* (25) obtained slight infection of *L. angustifolium*, altho it evidently was not a congenial host; and Miss Hart (16) obtained successful infection of *L. rigidum* but not of *L. lewisii* with rust from cultivated flax. The writer, also, obtained negative results in attempts to infect *L. lewisii.* Arthur apparently must have had a different form of rust. Attempts to infect *L. perenne* and *L. grandiflorum* were also unsuccessful.

In 1906 Arthur (3) demonstrated that *M. lini* was eu-autoecious. He inoculated *L. lewisii* and *L. usitatissimum* with overwintered teliospores from cultivated flax and obtaind pycnia and aecia on both hosts. Arthur pointed out the obvious significance of his discovery on the control of the disease. Since then pycnia and aecia have frequently been found in the field. The uredinial and telial stages, however, are most familiar and most destructive. The former occurs as orange-yellow pustules on all green parts of the plant, especially on the leaves.

The telia are most conspicuous on the main stem and branches, where they form black, usually swollen, incrustations, altho they also occur on leaves, sepals, and bolls.

EPIDEMIOLOGY OF FLAX RUST

The aecial stage usually appears during the latter part of June in Minnesota and adjacent states, June 20 being the earliest date on which the writer has found rust in the field in Minnesota. The initial infections are few and inconspicuous. The uredinial or repeating stage usually does not appear until early July. Then several "generations" of spores must be produced before rust becomes abundant and generally distributed. Since each "generation" requires approximately ten days to develop, the disease usually does not reach its maximum severity until late July or early August. As the flax matures, the telial stage of the rust gradually replaces the uredinial stage. The uredinial stage, however, may persist on volunteer flax plants until killing frosts occur. Viable urediniospores were collected on volunteer flax in Minnesota in 1924 as late as November 11, after several severe frosts had occurred. There is no indication that the urediniospores overwinter and infect flax the following spring. Teliospores, however, readily overwinter and produce the inoculum (basidiospores) for initial infections in the spring.

An experiment was made to determine if differences in soil water level on peat would have any effect on rust development. The same variety of flax was sown on plots having different soil water levels varying approximately from one to five feet from the surface. The flax plants were shortest and least thrifty on the five-foot water level, most vigorous on the intermediate water levels, and matured first and were moderately vigorous on the one-foot water level. As shown in Table I, rust infection was considerably lighter on the flax on the two extreme water level plots than on that on the intermediate water levels. In general, where the plants were most vigorous, rust was the heaviest. Regulation of the soil water level could hardly be recommended, therefore, as a control measure for rust. Considering both the growth of the plants and the severity of the rust, maintenance of the soil water level relatively near the surface seems to be preferable to the other extreme.

TABLE I

EFFECT OF DIFFERENT SOIL WATER LEVELS ON THE DEVELOPMENT OF FLAX RUST*

Water level	Per cent rust			
	Saginaw flax 1923	Saginaw flax 1924	Winona flax 1925	3-year Av.
1-foot	23	10	35	22.7
2-foot	50	13	75	46.0
3-foot	70	18	70	52.7
4-foot	55	15	70	46.7
5-foot	27	13	30	23.3

* Water level controls were installed and maintained by members of the Division of Agricultural Engineering, University of Minnesota, to whom grateful acknowledgment is made for their kind co-operation. Actual levels at which water was held in 1925 were 1.1, 2.1, 3.1, 3.9, and 4.5 feet, respectively.

VARIETAL RESISTANCE

Differences in resistance of varieties of *L. usitatissimum* to *M. lini* have been noted by several workers. Bolley (6), as early as 1903, noticed that different strains of flax reacted differently to rust. Sydow *et al.* (27) reported that European varieties remained free from rust in India while indigenous varieties were severely attacked. Eriksson (12) noted that different sorts showed varying susceptibility. Butler (8) mentioned a variety at Pusa, India, which had never been attacked. Westerdijk (30) stated that rust was known in Holland only on the white-blossomed flax. Girola (15) pointed out that "Lino mal Abrigo" (a group of Argentine varieties having medium-sized seed) was noted for its resistance to "polvillo." Howard (18) reported that of three classes of flax varieties (large-seeded, medium-seeded, and small-seeded) grown at Pusa, India, varieties of the last class did not suffer from rust and other diseases. Dorst (11) recently isolated rust-resistant strains of fiber flax in Holland, and Dillman (10) reported that certain Argentine flaxes were nearly immune from rust in the United States.

In these investigations, varietal tests have been made for several years, and distinct differences in varietal resistance have been found. The principal rust nursery has been on peat soil near St. Paul, since rust usually develops abundantly each year on flax grown on the low-lying peat bogs, whereas it often is much less prevalent on flax on higher land. Previous to 1924, this nursery was at Clearspring, Minn., while in 1924 and 1925 it was at Coon Creek, Minn. Infected straw from the previous year's crop was spread over the plots to increase the inoculum, and in 1924 and 1925 the plants were dusted or sprayed with fresh urediniospores from the greenhouse. In 1924 several varieties were tested also at Mandan, N. D., and at East Lansing, Mich., but no artificial inoculum was applied to these plots. Rust, however,

did not develop at East Lansing, so no data were obtained there.[2] The varieties were also artificially inoculated in the greenhouse as a check on the field results.

The most important result of these tests was the finding of varieties and strains of flax entirely immune from rust (17) (Plate I). In tests made in 1921 and 1922, Barker[3] noted that Chippewa, Minn. 182 (5) showed some resistance, and that a lot of commercial large-seeded Argentine flax obtained from the linseed mill of the Pittsburg Plate Glass Company, at Red Wing, Minn., was immune. The writer has subsequently isolated numerous immune pure lines from this and other samples of Argentine flax obtained from the Red Wing linseed mill and from the American Linseed Company, of New York. Most of these have large dark blue flowers and large brown seeds, but several other distinct types are represented. In addition to the blue-flowered sorts, immunity has also been found in white-blossomed yellow-seeded varieties. For instance, Ottawa 770B, a Canadian variety obtained in 1923, has been consistently immune in all tests. This variety has small white flowers with crinkled petals, yellow seed, and moderately long stems. Immune strains have also been found in Williston Golden, a short-stemmed variety having rather large white flowers and yellow seed. Several other varieties or strains, mostly of the large brown-seeded Argentine type, obtained from A. C. Dillman, Agronomist in charge of Seed Flax Investigations, United States Department of Agriculture; and several varieties obtained from India by A. C. Arny, of the Division of Agronomy, University of Minnesota, have proved immune or highly resistant in tests made in Minnesota.

Practically all varieties of seed flax commonly grown in the United States, including such wilt-resistant varieties as North Dakota No. 114 and Winona (Minn. No. 182), are susceptible to rust. All strictly fiber varieties so far tested, such as Saginaw, also are susceptible. However, there is considerable variation in the degree of infection on varieties classed as susceptible in the field. Such differences are often much less pronounced when seedlings are inoculated in the greenhouse.

Of the varieties found immune, Ottawa 770B most nearly approaches the fiber type. The stems of this variety, however, are too short and coarse for a good fiber variety. It was thought that the rust-resistant fiber strains which Dorst (11) isolated in Holland might

[2] Grateful acknowledgement is made for providing land and facilities for these tests to the Division of Agricultural Engineering, University of Minnesota, for the tests at Clearspring, Minn.; the Division of Soils, University of Minnesota, for those at Coon Creek, Minn.; A. C. Dillman and J. C. Brinsmade for those at Mandan, N. D.; and Dr. A. D. Suttle for those at East Lansing, Mich.

[3] Dr. H. D. Barker, formerly of the Division of Plant Pathology, was in charge of the early work on the flax rust project, under Dr. E. C. Stakman.

be valuable in the United States. Dorst kindly sent five of his selections to the writer. One of these had never shown rust, one was very resistant, two were fairly resistant, and one was susceptible in Holland. They were tested in the greenhouse at St. Paul and in two places in the field in Minnesota, but in each test all five strains proved susceptible. Evidently, therefore, they could not be recommended as rust resistant in the United States. The results can readily be explained if it is assumed that the rust on cultivated flax consists of several different physiologic forms and that forms capable of attacking these strains occur in Minnesota but not in Holland, where they were originally tested. In fact, similar distribution of forms has actually been demonstrated for *Puccinia graminis avenae* Erikss. and Henn., the cause of stem rust of oats, by Stakman, Levine, and Bailey (26). The variety White Tartar is resistant to forms of this rust occurring in the United States, but is entirely susceptible to two forms occurring in Sweden.

Table II gives the percentage of rust and relative wilt resistance in the field, in 1924, of five varieties which have been used in breeding investigations for the development of improved immune varieties.

TABLE II

Relative Rust Resistance of Five Varieties of Flax Grown in 1924 at Three Different Places and Relative Wilt Resistance at St. Paul

Variety	Percentage of rust*			Relative wilt resistance
	Clearspring, Minn.	Coon Creek, Minn.	Mandan, N. D.	Univ. Farm, St. Paul
Saginaw	15.0	30.0	27.5	MR†
Winona	20.0	41.6	27.5	R
Chippewa	25.0	30.0	25.0	R
Argentine selection	0.0	0.0	0.0	R
Ottawa 770B...	0.0	0.0	0.0	MR

* Artificial epidemic created at Coon Creek, natural epidemic at Clearspring and Mandan.
† MR, moderately resistant; R, resistant.

SELECTION

The simplest and most rapid method of producing rust-resistant varieties of flax, provided resistance could be found in plants of the desired type, is simply to select resistant plants and multiply them. Unfortunately, it is often impossible to find resistant plants which are otherwise desirable.

As rust is very destructive to fiber flax, numerous selections have been made from fiber varieties. The better fiber-flax varieties, such as Saginaw, were heavily inoculated both in the field and in the greenhouse. Plants which showed only traces of infection, and a few which remained entirely free from infection, were selected. The progenies

from these selections were later inoculated with rust and in most cases proved susceptible, indicating that the plants originally selected had merely escaped infection and were not truly resistant. None of the selections from the strictly fiber varieties proved immune. Some appear to be more resistant than the varieties from which they were selected, but it would seem much better to obtain through hybridization a selection entirely immune from rust.

Rust-immune varieties of seed flax already exist, as has been previously pointed out. Some of these doubtless can be improved by selection, and individual plant selections have been made from them with this end in view, as well as from numerous samples of commercial flax. Further improvement no doubt can be made by crossing the immune varieties with susceptible varieties in order to combine rust immunity with higher yielding ability, resistance to other diseases, and other desired characters.

HYBRIDIZATION STUDIES

As no rust-immune strains of fiber flax have yet been found in our studies, the most hopeful method of producing them is by crossing the susceptible fiber varieties with immune seed varieties and then selecting the segregates possessing the desired fiber characters and immunity from rust. It may also be possible to isolate, from the progenies of such crosses, immune fiber strains having the capacity for greater seed production than varieties of fiber flax now in use. These would be valuable for districts where both seed and fiber are saved. By selecting suitable parents, it should also be possible to combine wilt resistance and immunity from rust in desirable varieties of both fiber and seed flax.

Crosses have been made with these ends in view. The reaction to rust and wilt shown by the principal varieties used as parents in these crosses is given in Table II. It will be noted that the two immune parents, Argentine selection and Ottawa 770B, were immune from rust at three different places where they were tested. They have also been inoculated in the greenhouse with several other North American collections, including one from the fiber-flax section of Michigan and one from western Canada. They have been immune from all collections tested and are therefore valuable parents for crosses. The Argentine selection is also decidedly wilt resistant (Plate II, C.). Saginaw, the principal fiber parent used, is an exceptionally tall variety but is not a high seed producer. It is moderately resistant to wilt but quite susceptible to rust. Winona and Chippewa were used in crosses with the rust-immune varieties in order to combine their resistance to wilt with immunity from rust.

F_1 plants in all crosses made have been immune, indicating the dominance of immunity over susceptibility. Segregation for these characters occurred in the F_2, the type of segregation differing in different crosses. Numerous promising plants have been selected from this generation, and F_3 families of some of the Argentine crosses have been grown. Many of the selected plants were immune from rust and possessed other desired characters, indicating that immunity from rust can be obtained in different morphological types. There is every reason to believe that immune strains of both fiber and seed flax can be developed from these crosses. When the selections become homozygous or nearly so for rust immunity and other characters, they will be grown on wilt-infested soil and only the most wilt-resistant ones will be saved.

RELATION BETWEEN RUST RESISTANCE AND WILT RESISTANCE

Flax wilt caused by *Fusarium lini* Bolley is recognized as the most destructive disease of flax in the United States. As the pathogene is transmitted by the seed and can live saprophytically in the soil for many years, it is likely to follow the crop wherever it is grown. Fortunately, wilt can be controlled by the use of resistant varieties. Bolley (6), of the North Dakota Agricultural Experiment Station, was the first to recognize the importance of this in the United States, and several resistant varieties have subsequently been distributed by the experiment stations of North Dakota, Minnesota, and other states.

In developing rust-immune varieties of flax it obviously would be very desirable to have them resistant to wilt also. With this end in view, varieties under investigation for rust resistance have also been grown on soil infested with the wilt organism. The results of the combined studies indicate that there is no correlation between rust resistance and wilt resistance. Apparently resistance to the two diseases is not due to the same causes. Winona flax is resistant to wilt (Plate II, B and D) but is particularly susceptible to rust, whereas Saginaw is moderately resistant to wilt but susceptible to rust. On the other hand, certain strains of Williston Golden are immune from rust but are very susceptible to wilt (Plate II, A), while Ottawa 770B is immune from rust but moderately resistant to wilt. However, the fact that both wilt resistance and immunity from rust are found in strains of Argenine flax (Plate II, C) indicates that the two are not incompatible. It seems possible, therefore, to combine wilt resistance and immunity from rust in other varieties of seed flax as well as in fiber flax.

One of the major problems at present in connection with wilt-resistant varieties which have been distributed, is the matter of keeping them pure. Winona, for instance, differs from most of the seed flax grown in the Northwest only in the ability to resist wilt. Neither the seeds nor the plants can be distinguished in general appearance from many unselected lots of commercial flax which are susceptible to wilt. Mixtures or natural crosses might occur and not be detected until susceptible lines thus introduced had increased to such an extent as to result in serious losses from wilt. Careful certification, coupled with the education of the grower to the importance of growing his own seed, will largely avoid this danger. In addition, however, it would obviously be very desirable if some reliable test of the purity of wilt-resistant varieties could be made. Since wilt resistance is only relative, and varies with temperature and other environmental factors, a greenhouse test on disease-infested soil is not satisfactory for determining the purity of wilt-resistant flax. By combining in one variety both wilt resistance and immunity from rust, however, a very good check could be made of its purity by simply inoculating it with rust in the greenhouse. Large numbers of such tests could be carried out rapidly and with comparatively little labor. All plants susceptible to rust would constitute impurities. The present likelihood of mixture with other immune flax is not great. Immunity from rust would at least constitute an important distinguishing characteristic. Similar methods of detecting impurities have been used in other crop plants. The literature on the subject is summarized by Aamodt and Levine (1).

DISSEMINATION OF FLAX RUST WITH THE SEED

The attention of the writer was first attracted to this problem in 1922 by the experience of R. L. Davis, then in charge of fiber flax breeding investigations at East Lansing, Mich., for the office of Fiber Plant Investigations, United States Department of Agriculture. Mr. Davis stated that flax rust had occurred in his plots but once and then only on a few rows of a single (Japanese) variety. He immediately destroyed all the plants of the rusted variety and did not observe rust in his plots subsequently. The question naturally arose as to why there was rust on only one variety. The natural supposition was that it might have come from the seed. On looking over the literature on flax rust it was found that Pethybridge *et al.* (25), in Ireland, reported that flax rust could be transmitted to the following crop if fragments of the black or telial stage were sown with the seed.

The following experiment was made in 1924 to ascertain whether there was danger of transmitting flax rust with the seed in the United States. Winona flax was sown in three plots in an isolated corner of a sunflower field. Plot E was sown with seed which had been thoroly dusted with viable urediniospores. Clean seed was sown in Plot F, while the seed for Plot G was mixed with telial fragments approximately ⅛ inch in length. Each plot consisted of six rows, the three plots being separated only by two-foot alleys. They were sown at the same time, during the last week of May.

The earliest appearance of rust in these plots was noted on July 15 in Plot G. On July 1 careful counts were made of the percentage of rusted plants in the different plots. Six hundred plants, one hundred in each row, were counted in each plot. In spite of this careful survey, not a single rusted plant was found in any row of either Plot E or Plot F, that is, those sown with seed dusted with urediniospores and with clean seed, respectively. On the other hand, pycnia and aecia were found on plants in every row of Plot G, where telia were mixed with the seed, the percentage of infected plants in the different rows ranging from 1 to 10 per cent. Naturally, after these initial infections occurred, the rust tended to spread to the other two plots. After ten days a trace of uredinia was found in each of the other two plots. By September 20, rust was general on all three plots, as shown in Table III.

TABLE III

DATA ON TRANSMISSION OF FLAX RUST WITH SEED

Plot No.	Seed treatment	Date examined	Percentage of plants infected					
			Row numbers					
			1	2	3	4	5	6
E	Seed dusted with urediniospores	July 16	0	0	0	0	0	0
F	Clean seed	July 16	0	0	0	0	0	0
G	Telia mixed with the seed	July 16	2	4	1	10	4	2
E	Seed dusted with urediniospores	Sept. 20	30	46	58	56	40	36
F	Clean seed	Sept. 20	60	66	60	58	46	44
G	Telia mixed with the seed	Sept. 20	36	40	36	32	38	52

These results indicate that even tho the seed should become dusted with viable urediniospores and the flax sown immediately, there would be little danger of the seedlings becoming infected. Moreover, in the principal flax-growing areas of the United States the seed is always sown in the spring, so that urediniospores, which are relatively short-lived, would not survive the winter anyway. There seems little danger, therefore, of initial infections arising from this source, at least in the Upper Mississippi Valley. The results do indicate that flax rust can readly be carried from one crop to the next, not by the seed itself but with it in the form of bits of telia-laden straw. Even tho the

seed be planted in soil that has never before borne a crop of flax, the infection may be introduced with the seed in this way. A few initial infections could supply inoculum for a heavy infection of the whole field if conditions favorable to the pathogene should occur.

Another important matter arising out of the transmission of flax rust with the seed is the danger of introducing rust from other countries. With most rusts there is little danger of dissemination by the seed, but with flax rust there is a probability that it might be introduced in this way. Moreover, it is quite possible that a form of flax rust virulent on our resistant varieties, may occur in some other country and might be introduced with the seed. The fact already mentioned, that a selection of fiber flax introduced from Holland was susceptible to rust in this country while it never became rusted in Holland, indicates that flax rust in that country may be different from ours. Since Argentine selection and Ottawa 770B, which have been used largely as rust-immune parents in our breeding work, have proved immune to collections of rust made in Michigan, Minnesota, North Dakota, and western Canada, it is hoped that they will prove generally immune to flax rust occurring in this country and that no rust forms will be introduced from other countries which can attack these varieties.

CONTROL MEASURES

USE OF IMMUNE VARIETIES

The use of immune varieties offers the best means of controlling flax rust. As has been pointed out, immunity has been found in several types of seed flax and results indicate that it can be transferred to fiber varieties and more desirable seed varieties by crossing. Moreover, strains of seed flax have been found which are both resistant to wilt and immune from rust, so it seems possible to combine these qualities in strains of fiber flax and possibly in better strains of seed flax. The varieties in use at the present time, however, are nearly all susceptible to rust, so it will take several years to replace them even after immune varieties are introduced. While susceptible varieties are still grown, therefore, other measures should be taken to avoid damage from flax rust.

CARE OF THE SEED

Thoro cleaning of the seed is advisable, not only to remove foreign seeds but also as a preventive measure against rust and other diseases. Small bits of straw and chaff are almost invariably present in samples of uncleaned seed and these may carry inoculum to the following crop, especially if the previous crop was diseased. Diseases like wilt, pasmo, and browning may be transmitted on or in the seed itself, so that

cleaning can not entirely remove inoculum from the seed. But with rust, fragments of straw or chaff bearing telia are apparently the only carriers of inoculum which may be transmitted with the seed, and these can readily be removed by the fanning mill.

Many growers follow the practice of changing their seed every year or two. Not infrequently seed is obtained from distant sources and even from other countries. This is unwise, because rust may thereby be introduced into a district previously free from it. The same is true for several other destructive diseases of flax. In fact, if the seed is frequently changed, it is almost impossible to avoid the introduction of disease with it. The safest practice is for the grower to obtain seed of a recommended variety from his nearest experiment station and then to save his own seed for the following year, rather than purchase it each year from an outside source.

TIME OF SEEDING

Tobler (29) noted that under European conditions flax rust was more abundant late in the season and injured the stems of late-sown flax to a greater extent than those of early-sown flax. The same holds true in the flax centers of North America—rust is likely to be most destructive on late sowings. Early sowing is also a good preventive measure for wilt (5). In the north central part of the United States, flax can in most seasons be sown during the latter part of April without danger of serious injury from frost.

Table IV shows the relative severity of rust on flax sown at different dates at University Farm in 1923 and 1924. In 1923 rust was abundant in these plots, while in 1924 it was very light, infections occurring only on the plants in the seedings of the last two dates.

TABLE IV

Effect of Time of Seeding on Development of Flax Rust*

Time of seeding	Severity of rust	
	1923	1924
Usual time	T†	o†
10 days later	T	o
20 days later	L	o
30 days later	MH	o
40 days later	M	T
50 days later	H	T

* Data obtained from plots of the Division of Agronomy and Farm Management, University of Minnesota, through the courtesy of A. C. Arny.

† o, none; T, trace; L, light; M, medium; H, heavy.

Since flax rust does not become abundant under field conditions until midsummer, it is evident that early-sown flax will be exposed to infection for a much shorter period of its growth than late-sown flax.

If seedling flax plants are severely attacked by rust, they may be badly stunted and many of them may be killed. In Plate I, E and F, the effect of inoculating young seedlings of Winona and Saginaw flax in the greenhouse is shown in comparison with the immune Argentine selection, subjected to exactly the same conditions. Such severe injury would rarely occur in the field. However, when susceptible varieties are sown very late they may be so severely attacked that the plants may be killed or prevented from forming seeds. When immune varieties come into use, time of seeding will have no importance in this respect, as such plants are immune at all stages.

CROP ROTATION

With wilt-resistant varieties coming into more general use, some growers feel that they are safe in growing flax several years in succession on the same land. This practice, however, is conducive to the accumulation of rust and other diseases to which the wilt-resistant flax may be susceptible. As long as rust-susceptible varieties are grown, flax should not be sown on land devoted to flax the previous year. Corn or one of the legumes has been shown to be among the best crops to precede flax (10). As was first demonstrated by Arthur (3), the rust may overwinter in the telial stage on infected stubble and old straw left on the field, and is almost sure to infect susceptible varieties sown there the following year. If conditions become favorable for the pathogene, a serious epidemic may occur. Flax invariably should be grown in a rotation with other crops if at all possible.

CHOICE OF LAND

In addition to avoiding land that produced flax the previous year, it is well, from the standpoint of rust, to sow flax on relatively high land. On low-lying soils maturity is usually delayed and moisture conditions are more often favorable for rust infection than on higher land. For instance, in years when flax rust is relatively scarce on ordinary soils in the vicinity of St. Paul, it often is abundant on low-lying peat bogs; and infections, in general, are usually heavier every year on such land.

SANITATION

As long as susceptible varieties are grown, sanitary measures, consisting of the destruction or removal of infected straw after a diseased crop, will aid in the control of flax rust. This can be accomplished best by burning before the new crop emerges. If this is not done, the infected straw should at least be removed from the vicinity of fields intended for flax.

SUMMARY

1. Flax rust is an important disease of both seed and fiber varieties of *Linum usitatissimum,* but is especially important on the latter. It occurs in all the major flax-growing regions of the world.

2. The disease may reduce the yield of seed flax and may ruin the stems of fiber flax for fiber purposes and prevent proper retting.

3. *Melampsora lini* (Pers.) Lév. is the name commonly applied to the rust of *Linum spp.* However, distinct forms occur on different species of *Linum,* as noted by several workers. The rust of cultivated flax was described as a new variety, *M. lini* (Pers.) Lév. var. *liniperda* Körnicke, in 1865; and as a new species, *Melampsora liniperda* (Körnicke) Palm, in 1910. It apparently is deserving of at least the former rank. The rust is eu-autoecious, as was demonstrated by Arthur in 1906. All spore forms occur in the field, the uredinial and telial stages being most prominent and most destructive.

4. In Minnesota and neighboring states, the disease appears first during the latter part of June but does not assume epidemic form until late July or early August. The uredinial stage may persist until killing frosts occur, but apparently does not overwinter. The telial stage readily overwinters and starts the initial infections the following year.

5. In an experiment on a peat bog, flax was sown on five plots having water levels varying approximately from one to five feet from the surface. Heaviest infections of rust occurred on the intermediate water levels, where the flax was the most vigorous.

6. Altho all of the long-stemmed varieties of fiber flax thus far tested and most of the commonly grown varieties of seed flax are susceptible, sharp differences in varietal resistance occur. Immune varieties of both blue- and white-blossomed seed flax have been found. Thus numerous immune strains of large brown-seeded, blue-flowered, Argentine flax and immune strains of the yellow-seeded, white-blossomed Williston Golden flax have been isolated. Ottawa 770B, another white-blossomed, yellow-seeded variety having stems of intermediate length, also is immune.

7. Ottawa 770B and certain strains of Argentine flax were tested with rust from Canada and from several states of the United States and proved immune to all collections. They were used as parents in crosses with susceptible varieties of fiber flax, as selection alone of fiber varieties did not yield immune strains. Crosses were also made with wilt-resistant varieties of seed flax.

8. The F_1 plants of all crosses were immune, indicating that immunity is dominant in these crosses.

9. Segregation occurred in the F_2 and the behavior of the segregates indicates that it will be possible to combine immunity from rust with fiber characteristics or with other desired characters.

10. Certain strains of Argentine flax, in addition to being immune from rust, are highly resistant to wilt, so it should be possible to obtain wilt-resistance and immunity from rust in a fiber variety as well as in seed varieties.

11. Wilt-resistance and immunity from rust are not necessarily correlated. They apparently are determined by different causes. Winona, for instance, is resistant to wilt but susceptible to rust and strains of Williston Golden are very susceptible to wilt but immune from rust.

12. When both wilt-resistant and rust-immune varieties are in use, the latter characteristic will be of real value in testing them for purity. Greenhouse tests for immunity from rust can readily be made, whereas greenhouse tests for wilt resistance are not satisfactory.

13. The fact that certain rust-resistant strains and one apparently immune strain of fiber flax from Holland were susceptible when tested in the United States indicates that the rust of cultivated flax may be specialized into physiologic forms.

14. When bits of straw bearing telia were sown with the seed of a susceptible variety, infection of the following crop resulted. This confirms similar investigations conducted in Ireland, and emphasizes the importance of thoroly cleaning the seed. It also indicates the danger of introducing seed from other countries, as virulent forms of rust might be introduced in this way.

15. The use of immune varieties is the most promising control measure. As soon as suitable immune varieties are developed and generally distributed, other control measures naturally will cease to be of value. Because of the destructiveness of flax wilt, the immune varieties used should also be resistant to wilt.

16. While susceptible varieties are still in use, preventive measures should be taken to avoid flax rust: home-grown seed should be used where possible, and it should be thoroly cleaned to remove bits of straw; seeding should be done early; low-lying soils should be avoided; and on fields intended for flax, infected straw should be burned or removed before the new crop emerges.

LITERATURE CITED

1. Aamodt, Olaf S. and Levine, Moses N. Physiologic evidence on the genetic identity of natural and synthetic strains of wild emmer. Phytopath. 15:554-558. 1925.
2. Anderson, W. F. Brief notes on a few common fungi of Montana. Jour. Mycol. 5:30-32. 1889.
3. Arthur, J. C. Cultures of Uredineae in 1906. Jour. Mycol. 13:201. 1907.
4. ——— Coleosporiaceae, Urediniaceae, Aecidiaceae (pars.) No. Am. Flora 7:101. 1907.
5. Barker, H. D. A study of wilt resistance in flax. Minn. Tech. Bul. 20, pp.1-42. 1923.
6. Bolley, H. L. Flax and flax seed selection. No. Dak. Agr. Exp. Sta. Bul. 55, pp. 171-198. 1923.
7. Bucheim, A. Zur Biologie von *Melampsora lini*. Ber. Deutsch. Bot. Gesell. 33:73-75. 1915.
8. Butler, E. J. Fungi and diseases in plants. 1918.
9. Dewey, L. H. Principal commercial plant fibers. U. S. Dept. of Agr. Yearbook, 1903, pp. 387-398. 1904.
10. Dillman, A. C. Production of seed flax. U. S. Dept. of Agr. Farmers' Bul. 1328. 1924.
11. Dorst, J. C. Resistance of several strains of white-flowering flax to *Melampsora lini*. Report of the International Conference of Phytopathology and Economic Entomology, p. 33. 1923.
12. Eriksson, J. Fungoid diseases of agricultural plants. Bailliere, Tindall, and Cox, London. 1912.
13. Fuckel, L. Symbolae Mycologicae, p. 44. 1869.
14. Galloway, B. T. Notes. Jour. Mycol. 5:215. 1889.
15. Girola, C. D. Cultivo del lino en la Republica Argentina. Annales Soc. Rur. Arg. 54:105-112, 145-149, 189-198. 1920.
16. Hart, Helen. Some factors affecting the development of *Melampsora lini* (Pers.) Desm. (Abs.). Phytopath. 15:53. 1925.
17. Henry, A. W. and Stakman, E. C. The control of flax rust. (Abs.) Phytopath. 15:53. 1925.
18. Howard, Albert. The rusts of wheat and linseed. Ann. App. Biol. 7:382-383. 1921.
19. Léveillé, M. J. H. Disposition Methodique des Uredinees. Annales des Sciences Naturelles Botanique Ser. 3. 8:369-376. 1847.
20. Mathews, J. M. Textile fibers. John Wiley and Sons. 1924.
21. Miles, F. C. Fiber flax. U. S. Dept. of Agr. Farmers' Bul. 669. 1925.
22. Palm, Bjorn. Nya bidrag till Stockholmstraktens svampflora. Svensk. Botanisk. Tidskrift. Bd. 4. H. 1:(1-8). 1910.
23. Pethybridge, G. H. and Lafferty, H. O. Investigations on flax diseases. Jour. Dept. Agr. and Tech. Instr. for Ireland 20:342. 1920.
24. ——— and Rhynehart, J. G. Investigations on flax diseases. Jour. Dept. Agr. and Tech. Instr. for Ireland 21:1-22. 1921.
25. ——— Investigations on flax diseases. Jour. Dept. Agr. and Tech. Instr. for Ireland 22:3-20. 1922.
26. Stakman, E. C., Levine, M. N., and Bailey, D. L. Biologic forms of *Puccinia graminis* on varieties of *Avena* spp. Jour. Agr. Res. 24:1013-1018. 1923.

27. Sydow, H., Sydow, P., and Butler, E. J. Fungi Indiae orientalis. Annales Mycologici **4**:439. 1906.
28. Sydow, P. and Sydow, H. Monographia Uredinearum **3**:381-384. 1915.
29. Tobler, F. E. Zur Kenntniss der Lebens und Wirkungsweise des Flachsrostes. Faserforschung **1**:223-229. 1921.
30. Westerdijk, Johanna. Neueres ueber Flachskrankheiten Jahresbericht der Vereinung für Angewandte Botanik **16**:1-18. 1918.
31. Winter, G. Die Pilze. Rabenhorst. Kryptogamen Flora **1**:242. 1884.
32. Report of Joint Committee on Nomenclature. Phytopath. **15**:316-317. 1925.
33. U. S. Dept. of Agr. Bur. Pl. Indus. Plant Disease Survey. Plant Disease Bul. Supp. 27. 1923.
34. U. S. Dept. of Agr. Bur. Pl. Indus. Plant Disease Survey. Plant Disease Reporter Supp. 35. 1924.
35. U. S. Dept. of Agr. Bur. Pl. Indus. Plant Disease Survey. Plant Disease Reporter Sept. 15, 1925.
36. U. S. Dept. of Agr. Bur. Pl. Indus. Plant Disease Survey. Plant Disease Reporter Supp. 40. 1925.

EXPLANATION OF PLATES

PLATE I

Flax Varieties Susceptible to or Immune from Flax Rust

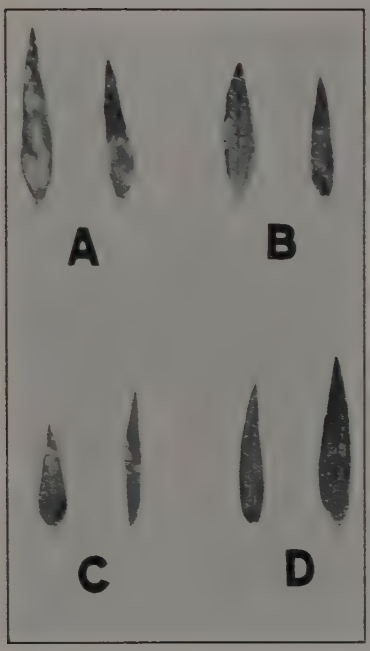
The leaves shown at A, B, C, and D were taken from plants of four different varieties of flax grown under the same conditions in the field and subjected to a heavy epidemic of rust. Leaves in A and C are from the susceptible varieties Winona and Saginaw, respectively, while those in B and D are from the immune variety Ottawa 770B and Argentine selection, respectively.

The effect of heavy inoculation of young seedlings in the greenhouse is shown in E and F. The tall plants on the left in both E and F are of the immune Argentine selection. The plants on the right in E are of Saginaw and on the right in F are of Winona. Saginaw is one of the best fiber-flax varieties and Winona one of the best wilt-resistant seed-flax varieties now in distribution in the United States. They are being bred with rust-immune varieties to combine this characteristic with their good qualities. The photograph was taken several weeks after inoculation.

PLATE II

A Portion of the Flax Wilt Nursery, University Farm, St. Paul, in 1924

Row C is Argentine selection, showing that it is highly wilt-resistant as well as being immune from rust. Rows B and D are checks of Winona, also highly wilt-resistant but susceptible to rust. Row A was sown with Williston Golden, a variety extremely susceptible to wilt but some strains of which are immune from rust. Varieties in the rows on either side of C show moderate susceptibility to wilt.



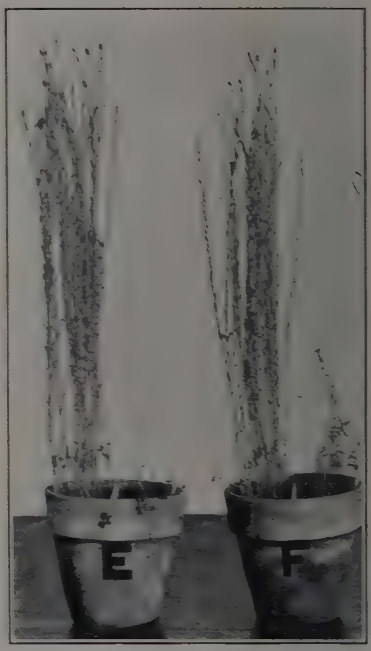


PLATE I



PLATE II

TECHNICAL BULLETIN 37 JULY 1926

University of Minnesota
Agricultural Experiment Station

Physiologic Specialization and Parasitism of Helminthosporium sativum

J. J. Christensen
Division of Plant Pathology and Botany

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	3
Objects of investigation	4
Studies on geographic distribution and prevalence	5
Physiologic specialization	11
Number of physiologic forms	11
Cultural characters of different forms	13
Rate of growth	14
Zonation	17
Pathogenicity of physiologic forms	20
Soil inoculations	20
Spike inoculations	23
Stability of the physiologic forms	26
Formation and germination of spores	35
Effect of environmental factors on fructification	35
Experiments on attenuation	37
Spore germination	38
Vitality of conidia	41
Overwintering of conidia	49
Effect of environmental factors on the development of the disease	50
Seasonal variation	50
Time of infection	50
Influence of soil moisture	52
Effect of time of planting on the development of *H. sativum*	56
Effect of time of planting on the development of *H. gramineum*	62
Predisposition of the host	63
Effect of seed treatment on the pathogene and the host	65
Effect of seed treatment on germination	65
Effect of seed treatment on growth of seedlings	69
Effect of seed treatment on the development of basal stem-rot and root-rot	70
Effect of seed treatment on yields	72
Varietal resistance	79
Control measures	90
Discussion and conclusions	91
Summary	93
Literature cited	96
Plates	100

PHYSIOLOGIC SPECIALIZATION AND PARASITISM OF HELMINTHOSPORIUM SATIVUM[1]

By J. J. Christensen

INTRODUCTION

The "*Helminthosporium* disease" of cereals, especially of wheat and barley, caused by *Helminthosporium sativum* P. K. and B. is prevalent and destructive every season in Minnesota. Moreover, it is widely distributed and causes serious losses. The writer has isolated the organism from material obtained from many states from Maine to Montana and Minnesota to Texas; also, from material obtained from several places in Mexico and Canada, and from one locality in Serbia. Other investigators (31 and 37) have reported the fungus from Canada, Argentina and Australia. Stakman (60), Christensen (18), Dosdall (24), and several other workers have called attention to the destructiveness of this disease, altho it is difficult to obtain accurate figures on losses.

Previous investigations have shown that the pathogene reduces crop yields in several ways. It lowers the percentage of seed germination, causes stunting and damping-off of seedlings, and premature death of ripening plants. It blights the seeds and floral parts and attacks the rachis and rachilla, thus preventing the caryopsis from developing normally. It causes severe spotting of leaves, stems, and glumes; and rots the roots, nodes, and basal portions of the stems.

Christensen and Stakman (20) pointed out that in 1924, in the hard red spring wheat region, *H. sativum* was the principal cause of premature death of wheat plants after heading. The disease was especially widespread and destructive in Minnesota. A disease survey of the state indicated that root- and basal stem-rots killed from 2 to 4 per cent of the plants of common wheat after heading, and from 5 to 15 per cent of durum wheat plants. In many fields of durum from 20 to 30 per cent of plants were killed, and in several others as many as 75 per cent had succumbed. A study of the parasitism of *H. sativum* is of practical importance and scientific interest, because the organism is a menace to wheat and barley culture and because it consists of many physiologic forms which mutate readily, especially on culture media (19). It is obvious that a knowledge of the number, cultural characteristics, parasitic capabilities, stability, and geographic distribution of physiologic forms is the essential basis for the development of permanent control

[1] The writer takes pleasure in acknowledging his indebtedness to Dr. E. C. Stakman, at whose suggestion this research was undertaken, for stimulating encouragement and helpful criticism during the progress of the investigation. He also desires to express his appreciation to J. H. Craigie and others to whom he is indebted for assistance of various kinds.

methods. It is especially important to obtain more information regarding the cause and frequency of mutations and variations, and of the behavior of the mutants in culture media and on host plants. It is important, also, to determine the effect of environmental factors on the development of the pathogene and on the susceptibility of host plants.

It is becoming axiomatic that several things must be known about a pathogene and its host plants in order really to understand the course of development of any plant disease.

The first things to understand thoroly are the pathogene and the factors affecting its development. Physiologic specialization has been discovered in so many different pathogenic fungi that one of the requisites in studying any pathogene is to determine the number and characteristics of physiologic forms. Furthermore, environmental factors are known to affect profoundly the behavior and structure of different physiologic forms (18, 43, and 57).

Even a routine study of a plant disease must therefore take into consideration a study of the physiologic specialization and the factors affecting the development of the pathogene. But the virulence and variability of the pathogene are only one phase of the problem. Host plants themselves may be greatly affected by the conditions under which they are growing. It is known that certain environmental factors may predispose plants to disease in a very real sense (22 and 27). Consequently, it also is important to know which factors render the plant more susceptible and to what degree the susceptibility can be changed by these environmental factors.

All these phases are important, and one should not be emphasized at the expense of the others. It must be realized that a disease is the result of the interaction between a pathogene and a host plant, both of which are living organisms with certain inherent and inherited tendencies which depend on the environment for their expression. The investigation was planned with these general principles in mind.

OBJECTS OF INVESTIGATION

The objects of the investigation were:

1. To ascertain the number and distribution of physiologic forms of *H. sativum*.

2. To ascertain the possible differences in virulence or pathogenicity of the different forms.

3. To determine the degree of stability of these forms under varying cultural conditions.

4. To investigate the effect of environmental factors on germination and vitality of spores.

5. To determine the varietal resistance of wheats to *H. sativum*.

6. To determine the effect of environmental conditions on the pathogenicity of *H. sativum* on wheat and barley.

7. To study the factors which predispose host plants to *H. sativum*.

8. To devise control methods other than the use of resistant varieties.

STUDIES ON GEOGRAPHIC DISTRIBUTION AND PREVALENCE

It has already been shown by Stakman (60), Christensen (18), and others that *H. sativum* is generally prevalent on small grains and grasses in the United States. It has been shown that the pathogene is abundant in many seed lots of wheat, barley, and rye (18 and 37). But it is logical to expect differences in the prevalence of the pathogene for a given region in different years and in different regions in the same year. For this reason the writer collected material from as many sources as possible, in order to obtain additional data on the geographic distribution and prevalence of the organism. This material consisted of infected seed lots, root systems, and culms of different varieties of grains. The method employed for isolation of the organism from various plant parts was similar to that already described by Christensen (18). Thousands of isolations of *Helminthosporium* were secured from various portions of small grains and numerous wild grasses.

There is a great variation in the percentage of seeds of wheat, rye, and barley infected with *H. sativum*. The amount of infection varies with locality, year, and variety of grain. At University Farm, St. Paul, Minn., durum wheat seed is usually more generally infected than the seed of common varieties. There also are striking variations in the percentage of seed infection by different organisms in different localities. Thus, in 1923, *Fusarium* predominated on seeds of Marquis wheat in southern Minnesota, while *Alternaria* and *Helminthosporium* were more prevalent in the northern part of the state. Hoffer (38), Henry (37), and others have recorded great variations in the percentage of wheat seeds infected with different organisms. Henry (37) isolated species of 20 genera of fungi from wheat seed, but he concluded that *Helminthosporium* was the most common cause of black-point of wheat.

During the winter of 1922-23, isolations were made from seed of 50 varieties and strains of barley which had been sprayed at heading time with a spore suspension of *H. sativum*. The percentage of seed infection was based on the number of colonies that developed as a

result of plating-out on potato dextrose agar 50 kernels chosen at random from each of the 59 varieties. The inoculated barley varieties were sown the following spring in seven-foot rows at the rate of 7 grams of seed per row. These seed lots were sown on heavy and light soils, and notes were taken on the relative resistance of the different varities to root-rot, basal stem-rot, and foliage infection. The barley varieties used are listed in Table III in Minnesota Technical Bulletin 21 (33, pp. 7-9). The seed was obtained from the section of plant breeding of the University. The results are summarized in Table I.

Data on the degree of root and basal stem infection were taken when the plants were almost mature. Notes on the degree of leaf infection were taken somewhat earlier, while those on seed blight were procured after the grains were threshed.

The symbols H (heavy), M (medium), L (light), T (trace), and o (absence of infection) are used to denote degree of infection. Plus and minus signs are used to indicate slight variations within each class. In order to make more exact comparison, the various degrees of infection were designated by numbers as follows:

o =1	L−=5	M−= 8	H−=11
T−=2	L =6	M = 9	H =12
T =3	L+=7	M+=10	H+=13
T+=4			

The numerical method is the same as that used by Hayes, Stakman, et al. (33), except that the smaller figures indicate resistance and the larger ones susceptibility.

Colonies of *Helminthosporium* developed from seed of all varieties, whether resistant or susceptible. The average percentage of *Helminthosporium*-infected seeds was 45.6. Calculations were made to determine if there was any correlation between the percentage of *H. sativum* on barley seed isolated in 1922 and the average root and foliage infection of the plants from the same seed lots grown on sandy soil at Coon Creek and heavy soil at University Farm, in 1923. From the data given in Table II, an apparently significant correlation coefficient of $+0.2905 \pm 0.0804$ was obtained. However, the reduction in variability, determined by the formula $100 \times (1 - \sqrt{1 - r_2}) = 4.3$, i.e., the effect of seed infection on the subsequent development of the disease, is more or less incidental.

TABLE I

SUMMARY OF ISOLATIONS OF *Helminthosporium sativum* FROM SEEDS OF 59 VARIETIES AND STRAINS OF BARLEY WITH VARYING DEGREES OF RESISTANCE

Species and varieties	Nursery stock or culture No.	Percentage of seeds infected, 1922			Degree of root and foliage infection with Helminthosporium, 1923*				
					Roots		Foliage		Average
		Total	Helmintho-sporium	Other fungi	U. Farm	Coon Creek	U. Farm	Coon Creek	
Hordeum vulgare									
Manchuria	Minn. 184	50	12	38	6	6	7	3	11
do	I-16-32	66	16	50	8	9	6	5	14
do	I-16-21	72	36	36	6	8	5	4	12
do	I-16-29	84	66	18	6	6	6	4	11
do	I-16-44	72	16	56	6	6	6	4	11
do	I-16-66	100	74	26	6	7	6	6	13
do	I-15-1	100	22	78	8	6	5	5	12
do	I-15-2	100	28	72	6	9	6	7	14
do	C 81	94	22	72	7	6	7	5	13
do	C 96	56	4	52	7	7	6	3	12
do	C 163	100	26	74	7	6	7	5	13
do	C 168	94	28	66	6	7	6	6	13
Trebi	III-20	96	70	30	10	10	10	6	15
do	I-16-14	100	32	64	8	9	7	6	18
Coast	III-20	100	90	10	9	12	6	6	17
Winter Club	III-20	...	..	..	6	8	9	9	16
Beldi	III-20	100	74	26	9	10	8	6	16
Mariout	III-20	100	70	30	9	9	13	6	18
Serbian	III-20	98	54	44	10	8	9	5	16
do	I-16-15	100	68	32	10	7	10	6	17
C. I. 894	I-16-84	78	24	54	10	7	6	4	14
Scotch	I-16-45	72	48	24	6	9	7	4	13
Sandrel	I-16-3	72	48	24	7	8	9	6	15
Odessa	I-18-2	94	66	28	6	6	8	6	13
Luth	C 93	100	8	92	7	6	7	5	13
Sandrel	C 104	100	80	20	10	9	6	6	16
Peruvian	III-20	100	58	42	11	7	9	5	16
Arequipa	C 267	100	74	26	10	12	10	8	20
Minsturdi	II-16-47	100	56	44	6	7	6	6	13
S. Afr. x Manch.	II-16-77	96	48	48	7	9	6	6	14
Highland Chief	I-16-31	100	38	62	10	12	8	5	18
Smooth Awn	C 284	100	42	58	9	10	8	6	17
Bay Brewing	I-18-3	100	68	32	9	10	9	9	19
Gatami	III-20	92	80	12	12	11	5	7	18
Lion	III-20	100	64	36	11	12	10	6	20

TABLE I—*Continued*

Species and varieties	Nursery stock or culture No.	Percentage of seeds infected, 1922			Degree of root and foliage infection with Helminthosporium, 1923*				
					Roots		Foliage		Average
		Total	Helmintho-sporium	Other fungi	U. Farm	Coon Creek	U. Farm	Coon Creek	
Hordeum vulgare									
Lion	I-16-13	88	54	34	11	12	9	7	20
Lion	C 270	100	70	30	9	10	9	7	18
Horsfords	III-20	100	42	58	7	9	8	6	15
H. v. horsfordianum		100	64	36	9	5	9	5	14
H. v. aethiops		100	56	44	7	7	7	5	13
H. v. coeleste		96	48	48	8	7	9	6	15
Black Hull-less		70	30	40	9	10	6	6	16
Nepal	III-20	26	8	18	9	7	8	3	14
Hordeum intermedium									
H. i. nudihaxtoni		62	20	42	11	7	12	7	19
H. i. cornutum		70	20	40	12	13	12	8	23
Hordeum distichon									
Hanna C. I. 906	III-20	100	50	50	6	9	6	6	14
Hanna	III-20	100	26	74	8	7	5	6	13
Hannchen	III-20	100	68	32	9	10	7	5	16
Boltons	III-20	88	12	76	9	8	5	5	14
Svanhals	I-13-21	100	58	42	6	8	6	6	13
Svansota	II-16-37	100	72	28	6	6	7	6	13
Chevalier	Minn. 230	100	74	26	6	7	5	6	12
Chevalier	III-20	...	..	..	6	9	5	6	13
H. d. n. persicum	C. I. 1003	100	70	30	8	12	8	6	17
do	S. P. I. 38316	100	54	46	9	12	8	6	18
Poppenheim		66	36	30	6	9	7	7	15
H. d. nigrinudum		...	..	..	12	12	6	6	18
Hordeum deficiens									
H. def. deficiens	C. I. 6684	74	7	67	7	6	11	6	15
do		100	38	62	6	6	12	9	17
H. def. steudelii		100	38	62	6	6	12	7	16
H. def. tridax		96	22	74	7	6	12	7	16
H. def. nudideficiens		100	46	54	12	13	9	6	20
Average		90.2	45.6	44.6	8.1	8.4	7.7	5.8	15.0

* 1=No infection 2=Trace— 3=Trace 4=Trace+ 5=Light— 6=Light 7=Light+ 8=Moderate— 9=Moderate 10=Moderate+ 11=Heavy— 12=Heavy 13=Heavy+

TABLE II

CORRELATION BETWEEN PERCENTAGE OF SEEDS OF 59 VARIETIES OR STRAINS OF BARLEY INFECTED WITH *Helminthosporium sativum* AND THEIR AVERAGE RESISTANCE FOR 1923 WHEN GROWN AT COON CREEK AND UNIVERSITY FARM

Average reaction at University Farm and Coon Creek, 1923	Percentage of seed infected in 1922									
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	
11		2		1			1			4
12	1		1					1		3
13	1		4		1	3	1	2		12
14	1	2	2		2		1			8
15	1			2	3					6
16			2	1		2	1	2		8
17				1	1		2		1	5
18				1		1	3	1		6
19		1					1			2
20					1	1	1	1		4
21										0
22										0
23			1							1
	4	5	10	6	8	7	11	7	1	59

$r = +.2905 \pm .0804$

In order to ascertain the variability in the amount of *Helminthosporium* infection due to chance, selection of infected seed, or environmental conditions in the same plots, isolations were made from nine replicated five-foot rows of the *Helminthosporium*-resistant Manchuria barley (Minn. No. 184). Fifty seeds from each row were sown on agar, as above. The variability which occurred is summarized in Table III. Thus, within a single variety of barley described as highly resistant (33), the *Helminthosporium*-infected seeds varied from 12 to 66 per cent, with an average of 42.8 per cent.

TABLE III

VARIABILITY IN PERCENTAGE OF SEEDS OF MANCHURIA BARLEY (MINN. NO. 184) INFECTED WITH *H. sativum*, GROWN IN REPLICATED FIVE-FOOT ROWS IN 1922, AND THE MEAN *Helminthosporium* REACTION OF THESE ROWS AT UNIVERSITY FARM AND COON CREEK IN 1923

No. of test	Percentage of seeds infected with Helminthosporium	Helminthosporium figure* average for University Farm and Coon Creek
1	12	11
2	42	13
3	44	12
4	54	14
5	66	12
6	66	12
7	48	12
8	14	13
9	40	11
Average	42.8	12.2

* Sum of averages of foliage and root infection. For explanation of figures, see footnote to Table I.

These results are in accord with the conclusions of Hayes, Stakman, et al. (33), that resistance is relative, not absolute; that the roots, foliage, and spikes of all varieties of barley may be infected, but in varying degrees. The degree of spike blighting is not correlated with the presence of the organism on the seed, but rather with the inherent susceptibility of the host.

Helminthosporium and Alternaria spp. constituted nearly all the fungi isolated from the barley seed. Relatively few colonies of *Fusarium* developed. It must be remembered that 1922 was not a bad scab year, at least very little scab developed in the vicinity of St. Paul. This perhaps accounts for the small percentage of *Fusarium*-infected seeds. A few other species of fungi belonging to different genera were observed. Several apparently new and distinct forms of *H. sativum* were secured.

Brownish lesions always developed on seedlings from kernels infected with *H. sativum* grown on agar, and these seedlings were eventually killed by the pathogene. *Alternaria spp.* were never observed to cause any decided browning while the plates were under observation.

Isolations from barley seeds procured from widely different sources indicated that species of fungi belonging to several genera can cause blighting. Inoculation experiments proved that at least 5 or 6 apparent species of *Helminthosporium* and one species of *Brachysporium,* besides numerous physiologic forms of *H. sativum,* can cause blighting of barley spikelets and grains. All species and forms concerned produce very similar discoloration on the spikelets and kernels. The relative virulence of the various forms of *H. sativum*—spike-blighting and root- and foot-rotting organisms—will be discussed later.

During the summer of 1924 there was considerable killing of wheat plants after heading (20). On account of the destructiveness of this disease, numerous isolations were made to determine the fungi responsible. The results are recorded in Table IV. *H. sativum* was by far the most prevalent organism on wheat. *Fusarium spp.* were more common on durum varieties than on common and emmer varieties or hybrids. Durums appear to be more susceptible to *Fusarium spp.* This is probably due to the fact that many of the isolations from the durums were made after the plants had been dead for some time and secondary organisms had had an opportunity to gain entrance. In durum wheat which had been grown on peat soil inoculated with *H. sativum,* from 95 to 100 per cent of the plants were killed after heading. Of the colonies obtained from these plants, 87.5 per cent were *H. sativum,* 3.1 per cent *Fusarium,* and 9.4 per cent other fungi. As the disease symptoms in these plants were identical with those so general in the

field, it seems probable that *H. sativum* was principally responsible for the serious blight epidemic on wheat in Minnesota during the summer of 1924. However, it should be remembered that Bolley (8), Stakman (61), Henry (37), and others have demonstrated that several species of fungi belonging to different genera can cause root-rot of cereals.

TABLE IV

SUMMARY OF RESULTS OBTAINED BY ISOLATING FUNGI FROM BASAL PORTIONS OF THE CULMS OF CEREALS AFTER HEADING IN 1924, IN MINNESOTA

Cereal	Number of isolations	Percentage of fungi isolated		
		Helminthosporium*	Fusarium	Other fungi
Wheat				
Common wheats	468	77.8	13.1	9.1
Durums	390	61.0	26.4	12.6
Emmer	96	67.7	20.8	11.4
Durum x Common hybrids	59	71.2	12.0	16.8
Total	1013	69.4	18.1	12.5
Oats				
Avena sativa	54	3.7	83.4	12.9

* Mostly *H. sativum*.

Altho *H. sativum* is so universally present on wheat and barley, it does not necessarily always cause appreciable damage. From Table I it will be seen that *H. sativum* was isolated from resistant as well as from susceptible varieties.

Isolations from oats indicate that *Fusarium spp.* probably were the primary cause of the blighting of oats after heading. Fields of oats were observed in Minnesota in which as many as 20 per cent of the plants were killed. These observations agree with the results of isolations made from oats seedlings during the last three years.

PHYSIOLOGIC SPECIALIZATION

NUMBER OF PHYSIOLOGIC FORMS

Helminthosporium sativum is a group species consisting of many elementary species or physiologic forms. In 1922, Stevens (62) and Christensen (18) showed that these forms differ in appearance and action on culture media and that differences in the size of spores of some forms can be detected by biometrical methods. Drechsler (26), Dosdall (24), and others also consider *H. sativum* a group species.

A systematic survey has never been made to determine the existing number of physiologic forms, and information regarding their pathogenicity, especially, is lacking. For these reasons the writer attempted to determine the number of forms and their characteristics.

It was found that they can be differentiated by the following criteria: cultural characteristics; rate of growth; thermal relations; amount of sporulation; zonation; the readiness with which they mutate; and, lastly, their pathogenicity.

All physiologic forms used in the following studies were derived from single spores. The method of procedure has been described elsewhere (19).

Stock cultures were grown for the most part on potato dextrose agar. These were kept either in the icebox at 7° to 10° C., or at room temperature, 18° to 23° C.

In Table V are given the form number, the host, the part of the plant from which isolated, the locality, the year, and the source of the culture for each of the 37 forms used.

More than 50 apparent forms were studied. Of these, 37 were studied in detail.

TABLE V

SOURCES OF 37 PHYSIOLOGIC FORMS OF *Helminthosporium sativum*

Form	Original host	Plant part from which isolated	Locality	Year collected	Previous history*
1	Rye	Kernel	University Farm, St. Paul, Minn.	1919	Material collected by writer
2	Barley	Leaf	Duluth, Minn.	1920	Culture furnished by Louise Dosdall
3	Barley	Leaf	University Farm	1920	Material collected by writer
4	Wheat	Base of stem	Illinois		Culture furnished by F. L. Stevens, 1921
5	Wheat	Node	Saskatoon, Sask., Can.	1921	Culture furnished by A. W. Henry
6	*Dactylis glomerata*	Leaf	University Farm	1921	Material collected by writer
7	*Agropyron repens*	Leaf	Decorah, Iowa	1921	Material sent in
8	Corn	Seedling leaf	University Farm	1921	Material collected by writer
9	Wheat		Sydney, Australia		Culture furnished by C. O. Hamblin, 1921
10	Wheat	Base of stem	Edmonton, Alberta, Can.	1924	Material sent in by G. B. Sanford
11	Barley	Kernel	University Farm	1922	Material collected by writer
12	Barley	Leaf	Texas	1923	Material furnished by J. H. Martin
13	Wheat	Base of stem	Thief River Falls, Minn.	1921	Material collected by writer
14	*Agropyron smithii*	Leaf	University Farm	1921	Material collected by writer
15	Barley	Kernel	University Farm	1922	Material collected by writer
16	Wheat	Kernel	Argentine	1921	Culture furnished by A. W. Henry
17	*Elymus striatus*	Leaf	Minneapolis, Minn.	1921	Material collected by writer
18	Wheat		England		Culture furnished by F. T. Brooks
19	Wheat	Base of stem	Watertown, Minn.	1924	Material collected by writer

* Single spore isolations were made from all the cultures.

TABLE V—*Continued*

Form	Original host	Plant part which isolated from	Locality	Year collected	Previous history*
20	*Hordeum murinum*	Leaf	Serbia	1922	Material collected by E. C. Stakman
21	Wheat	Kernel	Ashby, Minn.	1923	Material sent in to Seed Laboratory
22	*Echinochloa crusgalli*	Leaf	University Farm	1921	Material collected by writer
23	Barley		New York	1923	Culture furnished by R. S. Kirby
24	Barley	Leaf	Duluth, Minn.	1921	Material collected by writer
25	*Setaria glauca*	Leaf	Waconia, Minn.	1921	Material collected by writer
26	*Echinochloa crusgalli*	Leaf	Iowa	1921	Material sent in
27	Barley	Kernel	University Farm	1922	Material collected by writer
28	Oats	Base of stem	Glencoe, Minn.	1924	Culture furnished by E. B. Lambert
29	Oats	Leaf	Maine	1924	Material sent in by R. Bonde
30	Wheat	Foot	Cape Town, Africa		Culture furnished by H. J. Hynes (originally from R. Davis) 1924
31	*Bromus inermis*	Leaf	Buffalo Lake, Minn.	1921	Material furnished by E. C. Stakman
32	Durum wheat	Stem	University Farm	1919	Culture furnished by Louise J. Stakman
33	Wheat	Base of stem	Bemidji, Minn.	1924	Material collected by writer
34	Barley	Kernel	University Farm	1922	Material collected by writer
35	Wheat	Base of stem	Oklahoma	1923	Material furnished by E. H. Ostrom
36	Oats	Base of stem	Crookston, Minn.	1924	Specimen sent in by J. G. Leach
37	Barley	Kernel	University Farm	1922	Material collected by writer

* Single spore isolations were made from all the cultures.

CULTURAL CHARACTERS OF DIFFERENT FORMS

In order to compare their cultural characters, the 37 forms were grown on two different media: a 1 per cent potato dextrose agar; and a similar medium in which oatmeal, rice, and cornmeal were substituted for the potato as a nutrient base. Some forms were grown on other media also. Triplicate plates of each medium were inoculated with each form. Small, and as nearly as possible equal, portions of medium containing mycelium, and usually also spores, were used as inoculum in each case. The plates were of uniform size and contained the same amount of medium, usually 18 cc. The agar was made up in one lot, tubed, sterilized, and poured at the same time. After inoculation, the plates were placed on the same table in the laboratory and kept at room temperature. Thus all were subjected to the same general environmental conditions. The triplicate colonies of the same

forms on the same medium were always alike, unless accidentally contaminated by other organisms. It was noticed that a small colony of bacteria sometimes profoundly affected the growth of certain forms. In the immediate vicinity of colonies of foreign organisms, sporulation was often stimulated, and the morphology of the mycelium was occasionally changed considerably.

The 37 forms listed in Table V can be differentiated on cultural media macroscopically by the following characters: rate of radial growth; relative amounts of submerged and aerial mycelium; nature of mycelial growth, whether woolly or cottony, etc.; zonation, whether lacking, prominent, moderate, or faint, and the frequency and distance apart of the zones; conidial production, whether absent, scarce, moderate, or abundant; conidial clusters; and color of mycelium from white to black with intervening gradations and tints of other colors. The length, width, shape, and septation of the conidia, also, are different in some of the forms.

Dosdall (24), Christensen (18), and Stevens (62) have shown that cultures of *H. sativum* grown on different media and on the same media but under different environmental conditions, were changed greatly in habit of growth, structure and appearance of colonies, and morphology of the spores. However, such changes are only temporary and are not inherited. This phenomenon has been observed by numerous workers in various saprophytic and parasitic organisms.

It is evident from Plates III and IV that cultural characters of different forms of *H. sativum* differ greatly from each other on the same medium. The cultural characters of the same forms also are different on different media. The colonies of many forms were so strikingly different in general appearance that one was prone to separate them into different species. However, their similarity on another medium forbade such a reclassification.

RATE OF GROWTH

The amount of growth of the forms on the two media was measured on the 3d, 6th, and 11th days after inoculation. The results are presented in Table VI. It has been shown previously (18) that there are marked variations in rate of growth of physiologic forms of *Helminthosporium* on the same and on different media. On potato dextrose agar, during a period of 11 days, Forms 15, 13, 19, and 23 increased in average diameters 8.7, 5.2, 2.2, and 1.6 millimeters respectively, while on oatmeal-rice-cornmeal agar the rate of increase for the same forms was 3.1, 5.2, 4.9, and 2.0 mm. respectively. It is apparent

from Table VI that one form may grow extremely rapidly on one medium and very slowly on another. Another form may behave in exactly the opposite manner on the same media (Plates III and IV).

TABLE VI

RATE OF GROWTH OF 37 PHYSIOLOGIC FORMS OF *Helminthosporium sativum* ON TWO DIFFERENT NUTRIENT MEDIA

Form No.	Diameter of colonies, mm.*									
	Oatmeal-rice-cornmeal agar					Potato dextrose agar				
	Age, days									
	3	6	8	11	Av.	3	6	8	11	Av.
1	16	31	38	47	4.3	15	35	45	58	5.3
2	17	33	35	45	4.1	17	41	55	71	6.4
3	16	31	37	45	4.1	11	22	37	46	4.2
4	24	41	47	50	4.5	16	22	23	31	2.8
5	21	54	59	37	3.3	12	30	38	48	4.4
6	19	31	36	44	4.0	19	39	56	66	6.0
7	21	62	88	96+	8.7+	8	25	35	52	4.7
8	25	45	54	63	5.7	15	36	50	68	6.2
9	17	26	30	38	3.4	12	20	27	33	3.0
10	15	26	35	40	3.6	17	46	56	74	6.7
11	21	52	69	95	8.6	12	24	33	45	4.1
12	28	36	45	57	5.2	13	30	37	48	4.3
13	17	39	48	57	5.2	14	33	40	58	5.2
14	25	58	67	82	7.4	19	33	43	58	5.2
15	21	52	70	96	8.7	7	14	20	34	3.1
16	16	31	39	46	4.2	13	35	48	65	5.9
17	20	37	43	50	4.5	18	34	43	55	5.0
18	12	26	34	57	5.2	13	32	41	56	5.1
19	10	16	20	24	2.2	15	30	40	54	4.9
20	11	15	19	24	2.2	12	27	34	45	4.1
21	24	67	86	96	8.7	10	30	45	58	5.2
22	18	32	38	46	4.2	9	27	38	51	4.6
23	12	14	15	17	1.6	6	14	18	22	2.0
24	16	26	33	40	3.6	13	32	43	59	5.4
25	15	27	36	46	4.2	12	31	44	64	5.9
26	22	59	83	95	8.6	17	44	58	73	6.7
27	18	28	39	54	4.9	14	33	44	55	5.0
28	17	26	32	42	3.6	17	33	41	53	4.9
29	16	29	35	45	4.1	16	34	45	58	5.3
30	19	24	27	31	2.9	15	31	41	54	4.9
31	14	24	30	37	3.4	16	33	43	58	5.3
32	19	37	43	50	4.6	14	33	48	69	6.3
33	16	25	29	33	3.0	10	17	19	26	2.4
34	17	27	33	40	3.7	12	30	45	62	5.6
35	17	36	48	63	5.8	17	36	46	61	5.5
36	17	32	33	41	3.8	15	21	27	36	3.3
37	20	31	36	48	4.4	13	34	43	60	5.5
Av.	18.1	34.8	42.9	51.8	4.7	13.6	30.3	40.2	52.9	4.8

* Measurements based on average of three colonies.

To determine the degree of correlation in rate of growth of the 11-day-old colonies of the 37 forms on the above-mentioned media, the correlation coefficient was computed. The results are given in Table VII.

TABLE VII

CORRELATION BETWEEN RATE OF GROWTH OF 37 FORMS OF *Helminthosporium sativum*, 11 DAYS OLD, ON POTATO DEXTROSE AGAR AND ON OATMEAL-RICE-CORNMEAL AGAR

Growth on oatmeal-rice-cornmeal agar (in millimeters)	Growth on potato dextrose agar (in millimeters)						
	21-30	31-40	41-50	51-60	61-70	71-80	
11-20	1						1
21-30			1	1			2
31-40	1	1	1	3	1	1	8
41-50		1	1	6	4	1	13
51-60		1	1	3			5
61-70					2		2
71-80							0
81-90				1			1
91-100		1	1	2		1	5
	2	4	5	16	7	3	37

$r + .1366 \pm .1089$

The calculated coefficient $+0.1366 \pm 0.1089$ is only slightly larger than its probable error. This indicates that the rate of growth of different forms is influenced differently by the kind and amount of nutrient.

The average rate of growth on both media, as well as pathogenicity tests, indicates that there is no correlation between the degree of virulence and the rate of growth on culture media. Thus, Form 23 made an average growth of 1.8 mm. per day for 11 days, altho it possesses a higher degree of virulence than Form 2, a relatively weak strain, which made a growth of 5.3 mm. per day. On the other hand, Form 11 grows more rapidly than Form 2, and is also more virulent.

The difference in rate of growth between slowly and rapidly growing forms on both media may be due partly to temperature relations. Dosdall (24) found that the minimum temperature for growth of *H. sativum* was near 0° to 2° C., the maximum between 35° and 39° C., and the optimum between 24° and 28° C. Preliminary tests with several forms indicate that the temperature relationship is not the same for all forms. For instance, Form 1 would not grow above 32° to 33° C., and grew very poorly at 29° to 30° C. Johnson (39) has recently shown that forms of *H. graminicum* Rab. are strikingly different in their cardinal temperature relationships.

ZONATION

The differences in zonation of different forms on potato dextrose agar and on oatmeal-rice-cornmeal agar are summarized in Table VIII. It is evident that zonation was pronounced in some forms, but lacking in others (Plates III and IV). In some forms zonation was due to variation in the quantity of conidia and to aerial mycelium or to both. Variation in color of mycelum often influenced the conspicuousness of the zones. The expression of color is influenced to a marked extent by temperatures and nutrients.

TABLE VIII

VARIABILITY IN NUMBER OF ZONES OF 37 FORMS OF *H. sativum* IN 11-DAY-OLD CULTURES GROWN AT ROOM TEMPERATURES

Form No.	Oatmeal-rice-cornmeal agar		Potato dextrose agar	
	No. of zones	Character of zones	No. of zones	Character of zones
1	8	Pronounced	7	Pronounced
2	8	do	9	do
3	8	do	5	Faint
4	5	do	7	Faint to pronounced
5	9	do	8	Faint
6	8	do	8	do
7	0	Absent	3	do
8	8	Pronounced	7	do
9	7	do	7	Faint to pronounced
10	8	do	7	Pronounced
11	6	Faint	0	Faint
12	8	Pronounced	6	Faint to pronounced
13	4	Faint	7	Faint
14	8	do	8	Faint to pronounced
15	7	do	0	Absent
16	8	Moderate	7	Faint
17	7	Pronounced	8	do
18	8	Mod. to pronounced	8	do
19	4	do	5	do
20	8	Pronounced	8	do
21	3	Moderate	4	do
22	8	Pronounced	6	Faint to pronounced
23	3	Faint to pronounced	0	Absent
24	8	Pronounced	6	Faint to pronounced
25	4	do	4	do
26	4	Faint	4	Faint
27	8	Pronounced	7	Faint to pronounced
28	8	do	7	do
29	8	do	7	do
30	4	do	8	Faint
31	8	do	8	Pronounced
32	7	Moderate	7	Faint to pronounced
33	8	Pronounced	4	Faint
34	7	do	8	Faint to pronounced
35	7	Moderate	5	do
36	8	Pronounced	6	Faint
37	8	do	7	Faint to pronounced

Zonation has been attributed to various causes (5, 17, 36, and 63): short exposures to light, alternation of light and darkness, alternation of temperature, resting periods, staling products, mycelial crowding, alkaline media, and variation in amount of food.

Bisby (5) has reviewed previous studies and observations relating to zone formation in fungi and points out the lack of agreement among various workers. Bisby proved that zonation in cultures of *Fusarium discolor sulphureum* (Schl.) A. and W. could be caused by alternating light and temperature. He concluded that exposure of a culture of this organism to bright daylight for one-fourth to one-half second is sufficient to produce a zone. Exposure for 6 minutes to a twenty-five candle power carbon lamp at a distance of one meter was required to induce a noticeable ring, while exposure for about two minutes to a tungsten filament lamp of about the same candle power caused zone formation. Bisby states that "The light acts upon the outermost tips of the hyphae, and the phenomenon is, at least in part, another case of the effect of light upon growth." He induced ring formation by alternating temperature in constant darkness.

Chaudhuri (17), 1923, worked with *Verticillium albo-atrum* McA. and concluded that stale medium, one containing an old culture, and alkaline media, increased the sharpness of zones. Under certain conditions zonation could be prevented by raising the hydrogen-ion concentration. He also found that the organism produced zones in darkness only at 25° C. but, on exposing the cultures to constant light, zonation occurred at lower temperatures (21° to 23° C.).

Data on the zonation of *H. sativum* in relation to environmental conditions are given in Tables IX and X. For the experiments summarized in Table IX, large test tubes, 25 x 2.5 cm. were used. Fifteen cc. of potato dextrose agar was poured into each tube and slanted so as to give a 15-cm. lateral surface, the center of which was inoculated. The tubes were then sealed by dipping the plugged end in melted paraffin in order to prevent drying out of the cultures and thus prolong the growing period. Duplicate cultures were made in every case. In making zonation tests the plate cultures were inoculated in the usual manner. Usually three or more plates were used for each set of conditions. In many cases the experiments were repeated several times. While the cultures were being interchanged they were necessarily exposed to daylight or lamplight. The controls were always exposed to the same light for the same length of time.

TABLE IX

RELATION OF TEMPERATURE AND LIGHT TO ZONATION OF *H. sativum* WHEN CULTURED IN LARGE TEST TUBES SEALED WITH PARAFFIN

Temperature, ° C.	Light relation	Zones
5-7 constant	Dark	o
10-12 do	do	o
16-18 do	Dark and diffused light (alternating)	o
21-22 do	Dark	o
24-25 do	do	o
29-30 do	do	o
32-33 do	do	o
20-22 do	Light (lamp)	o
5, 12, and 29 alternating*	Dark	+
12 and 29 alternating	do	+
18, 12, and 29 alternating	Dark and diffused light at 18, 12, and 29	+
32, 12, and 29 alternating	Dark	+
29 and 12 alternating	do	+
20 and 30 alternating every 12 hours	Diurnal change	+

* First figure represents temperature at which culture was first kept.

TABLE X

EFFECT ON ZONATION OF *H. sativum*, FORM 1, ON DIFFERENT MEDIA, AND VARIOUS AMOUNTS OF THE SAME MEDIUM, KEPT UNDER DIFFERENT ENVIRONMENTAL CONDITIONS

Medium					
Kind	Amount, cc.	Tempera-ture, ° C.	How kept	Light relation	Zones
Potato dextrose agar	30	5-7	Constant	Dark	o
do	20	5-7	do	do	o
do	20	10-12	do	do	o
do	30	24-25	do	do	o
do	20	24-25	do	do	o
do	20	24-25	do	do	Few zones at edge of old colonies
do	30	24 and 29	Alternating	do	+
do	20	24 and 29	do	do	+
do	20	20 and 30	do	do	+
do	20	20 and 30	do	Diurnal change	+
Oatmeal-rice-cornmeal agar	20	24-25	Constant	Dark	o
do	20	20 and 30	Alternating	do	+
do	20	24 and 12	do	do	+
do	20	20	Constant	do	Few zones at edge of old colonies
do	20	12 and 24	Alternating	Light	+
do	10	20-22	Constant	Dark	+
do	10	20-22	do	Diurnal change	+
do	15	20-22	do	Dark	+
do	15	20-22	do	Diurnal change	+
30	30	20-22	do	do	o
do	20	20-22	do	do	+ (weak)
Carrot agar	20	24-25	do	Dark	o, but one plate with zones at edge of old colony
do	20	24 and 29	Alternating	do	+
do	20	20 and 30	do	do	+

The exposure of cultures of *H. sativum*, Form 1, to daylight or to lamplight for from 5 to 15 minutes did not cause zonation, but alternating temperatures in constant light or darkness resulted in ring formation. A variation in temperature of 5° C. (25° to 30° C.) for 24 to 48 hours was sufficient to induce zonation. Alternation of temperature

from 20° to 30° C. at intervals of 10 to 12 hours resulted in zone formation. Under certain conditions alternation of diffused light and darkness at constant temperature also induced zonation. The exposure of cultures to variations in temperature from 20° to 30° C. in darkness, and to the same temperatures but to diurnal changes of light and darkness, resulted in the same number of zones. Those under the last named condition were much more distinct.

Increased depth of medium influenced the size and compactness of zones. Zones were produced in petri dishes containing from 10 to 15 cc. of oatmeal-rice-cornmeal agar, at constant temperature in darkness or in continuous light. But no zones developed in dishes containing 30 cc. of agar, unless the medium prevented rapid growth. In these cases zoning took place only after the culture had become one or two weeks old. However, no zonation occurred in test tubes, or in petri dishes when kept for several weeks at constant temperatures of 29°, 10°, and 6° C.

Thus it is apparent that the type of zone and the rate of formation vary strikingly on the same and on different media in different physiologic forms of *H. sativum*. Form 1 sometimes produced zones at constant temperature and in the absence of light in cultures, perhaps because of the production of staling substances by the fungus.

A change in temperature from one favorable to growth or sporulation of the organism to an unfavorable one caused the formation of conspicuous zones.

It is obvious, therefore, that the 37 physiologic forms of *H. sativum* behave differently physiologically, but the most important question is, Are they different pathogenically?

PATHOGENICITY OF PHYSIOLOGIC FORMS

Christensen (18), in 1921, noted variations in the degree of pathogenicity of certain physiologic forms of *H. sativum*. Dosdall (24) found a difference in degree of severity with which two strains of *H. sativum* attacked Lion barley and Marquis wheat. Henry (37) observed variation in virulence of strains of *H. sativum* obtained from different sources and was able to distinguish 4 strains of "small-spored Helminthosporia" by their differences in pathogenicity on wheat.

SOIL INOCULATIONS

The writer made tests of the comparative virulence of physiologic forms by inoculating soil in four 4-inch pots with pure cultures. Twenty-five seeds were planted in each pot, so that 100 seeds of each cereal variety were used in each test. The wheat seeds were treated by the Jensen modified hot-water treatment. The barley was soaked for 2 hours in a 0.25 per cent solution of Chlorophol, an organic mer-

cury compound. The soil used was a mixture of three parts garden loam and two parts sand. All the soil for a given experiment was mixed in one lot and then steamed for 3 hours. The inoculum was grown in Erlenmeyer flasks on autoclaved seed of wheat and oats in a proportion of three to one by volume. An equal amount of inoculum was added to each pot of a series. Even the forms that grew slowly on ordinary culture media grew well on this medium. The same quantity of uninoculated wheat and oats mixture was added to the controls. The pots were all placed on a center bench in the greenhouse in order that all might receive the same amount of heat and light.

Data on the comparative pathogenicity of 26 forms on Marquis wheat (C. I. 3641), and Mindum (Minn. No. 470), a durum variety, are given in Table XI. A record was made of the number of plants which emerged and of the number which developed beyond the two-leaf stage. Both varieties were more or less susceptible to all 26 forms of the pathogene, but there were distinct and consistent differences in the virulence of different forms on both varieties of wheat. Forms 5, 8, 11, 13, and 15 were the most virulent, while Forms 3, 19, 21, and 26 were relatively weak. There also are intermediates between the two extremes.

TABLE XI

RESULTS OF INOCULATING SOIL GROWING MARQUIS AND MINDUM WHEAT IN THE GREENHOUSE WITH 26 PHYSIOLOGIC FORMS OF *H. sativum*

Form No.	Percentage of seeds producing seedlings										Total No. of plants which survived	
	Marquis					Mindum						
	Pot No.					Pot No.						
	1	2	3	4	Av.	1	2	3	4	Av.	Marquis	Mindum
1	20	28	28	24	25.0	16	20	24	36	24.0	4	10
2	36	16	28	36	29.0	48	32	24	32	34.0	17	21
3	36	80	56	60	58.0	32	63	48	40	46.0	47	32
4	20	8	8	4	10.0	12	20	16	44	23.0	1	7
5	0	0	0	1	0.2	0	0	1	0	0.2	0	0
6	28	8	4	8	8.0	28	16	8	28	20.0	47	32
7	24	32	12	32	25.0	12	20	28	28	22.0	22	21
8	8	0	4	0	3.0	0	0	8	0	2.0	2	2
9	20	20	20	16	19.0	24	32	28	8	23.0	13	8
10	24	28	24	4	20.0	28	24	28	32	28.0	3	14
11	0	4	0	0	1.0	4	0	12	4	5.0	1	2
12	16	36	36	8	24.0	20	16	28	32	24.0	14	22
14	8	16	12	12	12.0	4	16	20	8	12.0	11	10
15	4	0	12	0	4.0	4	4	4	8	5.0	3	3
16	16	8	12	6	10.5	20	20	36	24	25.0	6	13
17	24	12	16	24	19.0	24	36	24	28	28.0	11	19
18	20	28	24	24	24.0	20	32	8	12	18.0	6	9
19	40	60	36	36	43.0	36	40	24	48	37.0	26	25
20	36	20	20	32	27.0	16	12	36	20	21.0	17	9
21	36	40	60	56	48.0	76	52	56	72	64.0	45	59
22	32	20	12	12	19.0	28	52	35	20	32.0	9	20
23	4	28	16	12	15.0	44	8	8	24	21.0	9	7
24	32	24	32	36	31.0	8	24	28	32	23.0	30	19
25	12	8	24	4	12.0	44	12	28	36	30.0	8	14
26	76	64	80	76	74.0	76	48	56	64	61.0	72	59
Control	88	84	90	92	86.0	88	84	80	80	83.0	86	83

There are also differences in the virulence of the different forms on varieties of barley. Trebi (C. I. 936) and Chevalier (C. I. 278) were inoculated with all the forms. The results are given in Table XII. Notes were taken on the percentage of plants which emerged and on the percentage of seedlings with deformed and infected primary leaves in each pot. The averages of these readings are given in Table XII.

TABLE XII

RESULTS OF INOCULATING SOIL GROWING TREBI AND CHEVALIER BARLEY IN THE GREENHOUSE WITH 26 PHYSIOLOGIC FORMS OF *H. sativum*

Form No.	Percentage of germination*		Percentage of seedlings with deformed primary leaves†		Degree of stunting‡	
	Trebi	Chevalier	Trebi	Chevalier	Trebi	Chevalier
1	90	89	37	37	L+	L+
2	89	89	31	37	M—	L+
3	88	93	17	16	T+	T+
4	88	88	7	14	L—	L
5	63	77	82	69	H	H
6	83	96	25	20	L	L
7	84	90	5	7	L—	L
8	76	85	59	33	M+	M
9	79	73	65	60	M—	M—
10	81	94	40	26	L+	L+
11	74	77	91	92	H—	M+
12	96	92	31	24	M—	L—
13	63	74	79	54	M—	L+
14	76	84	48	37	L+	L+
15	65	69	67	59	M	L
16	84	84	67	29	M	M
Control I	86	91	1	1	o	o
17	75	83	32	20	L+	L
18	75	85	76	52	H—	M+
19	97	88	17	5	L	L—
20	69	86	85	86	M	M
21	78	82	12	8	T	T
22	93	93	27	14	L	L
23	79	79	53	44	M	L+
24	81	70	36	35	L	T+
25	80	81	17	17	T+	L—
26	66	77	42	40	T+	T+
27	87	95	30	17	L+	L—
28	90	87	34	26	L	L—
29	90	88	25	13	L	L
30	87	90	9	3	L—	L—
31	83	85	23	29	L+	L
32	82	84	39	22	L+	L+
33	87	88	63	63	M	M
34	80	88	69	60	H—	H—
35	81	90	50	34	M—	L+
36	77	87	69	69	H	H
37	81	76	78	66	H+	H+
Control II	95	95	1	0	o	o

* Average of four pots.

† Due to primary infection, leaves often destroyed or contorted, and very much shortened.

‡ Gross appearances. H=heavy, M=medium, L=light, T=trace, o=no infection.

The degree of stunting on one-month-old seedlings, based on general appearance at that time, is also indicated. It will be seen that many of the physiologic forms differ in their reaction on two varieties of barley.

Forms 5, 11, 34, and 37 were especially virulent in both varieties. Two of these, Forms 5 and 11, were virulent on wheat also. Altho Forms 3, 4, 30, and others were weakly parasitic, they all attacked barley slightly. In general, the same forms were also weak pathogenes on wheat varieties.

The correlation coefficients for the reactions of 37 forms on two varieties of barley were computed. The data are presented in Table XIII. The results show a correlation of $+0.9344 \pm 0.0139$. This indicates that there is a high degree of correlation between the behavior of the forms on one variety and that on the other.

TABLE XIII

CORRELATION BETWEEN PERCENTAGE OF SEEDLINGS OF TREBI AND CHEVALIER BARLEY WITH DEFORMED AND INFECTED PRIMARY LEAVES RESULTING FROM INOCULATING THE SOIL WITH 37 PHYSIOLOGIC FORMS OF *H. sativum*

Percentage of Trebi seedlings with deformed and infected leaves	Percentage of Chevalier seedlings with deformed and infected leaves										
	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100	
1-10	2	1									3
11-20	2	2									4
21-30		4	1								5
31-40		1	4	2							7
41-50				4							4
51-60				1	1						2
61-70			1			3	2				6
71-80						2	1				3
81-90							1		1		2
91-100										1	1
	4	8	6	7	1	5	4	0	1	1	37

$r = +.9344 \pm .0139$

SPIKE INOCULATIONS

In order to determine whether physiologic forms differed in their ability to attack above-ground parts, individual heads of Marquis wheat and a selection of barley, Colsess (obtained from Prof. W. T. G. Wiener, of the Manitoba Agricultural College), were inoculated in the field with 28 forms of the pathogene. Four partly emerged heads of wheat and 3 of barley were inoculated with each form by dipping the heads in a spore suspension. After inoculation the heads were covered with glassine bags which were left on the wheat plants for 2 weeks and on the barley for 3 weeks. About 1 cc. of water was injected into the bags one week after inoculation. Similar tests were made in the greenhouse, except that pieces of cotton moistened in the spore suspension were wrapped around the heads and then covered with glassine bags.

The results of these experiments are summarized in Table XIV. All forms used infected both wheat and barley. Thus, it is apparent that blighting of wheat and barley florets, glumes, seeds, and spikes is caused by numerous physiologic forms of *H. sativum* (Plate II, Figs. 1 and 2). In many cases the upper sheath and neck of the inoculated barley plants became severely infected. This undoubtedly happened because some of the inoculum passed down between the sheath and stem, an ideal place for infection owing to the retention of moisture. The low percentage of infection on wheat in the field may have been due to unfavorable conditions during incubation, since a considerably higher degree of infection appeared on the same varieties in the greenhouse.

TABLE XIV

RESULTS OF INOCULATING HEADS OF WHEAT AND BARLEY IN THE FIELD AND GREENHOUSE WITH VARIOUS PHYSIOLOGIC FORMS OF *H. sativum*

Form No.	Field						Greenhouse		
	Barley					Wheat	Stage of development		
	Spike infection* Head No.				Neck and upper sheath infection†	No. of spikelets blighted‡	Barley	Wheat	
	1	2	3	Av.			Milk	Flower	Soft dough
Control	o	T—	o	T—	o	Tr—	o	o	o
1	H+	H+	H	H+	H+	5	...	H	T
2	L	M	...	L+	L	1	...	...	...
3	T	L	T	T+	T+	.5	...	...	...
5	H—	M+	H	H—	H—	1	H	L+	T
6	L	M	L+	L+	M+	8	...	...	...
7	H—	M	M—	M	M+	1	...	o	o
8	M	L	M	M—	L+	2	M+	M—	T+
9	H+	H	H+	H+	H+	5	H—	H	H—
Control	o	o	o	o	o	1	o	o	o
11	H+	H+	M—	H	H+	3	...	...	...
12	H+	H	H	H	H	5	...	...	...
13	...	...	...	...	...	3	M—	M	L
14	M	H	L+	M	H	3	...	...	...
15	H+	H	H	H	H	2	...	...	...
16	H+	H	H	H	H	6	M—	L—	T—
17	M	M+	H	M+	H	2	M	H+	H—
18	H+	H	H+	H+	H+	3	H	H—	L+
20	M	L+	L	L+	M+	1	M—	L+	T+
21	H	M	M	M+	L—	7	...	...	...
Control	T	o	T—	T—	o	..	...	...	...
22	H—	M—	H—	M+	H—	2	...	...	...
23	M	L+	L	L+	M—	o	...	...	...
24	H	H	H	H	H	5	...	...	...
25	M	L	L—	L	M—	2	...	...	...
26	H	L	M	M	M	1	...	...	...
27	H+	H+	H+	H+	H+	5	...	...	...
31	L—	M+	H—	M	H	2	...	...	...
34	H+	H+	M+	H	H+	..	..	...	...
37	H+	H+	H+	H+	H+	8	...	...	...

* Symbols indicating degree of infection:
H+=all spikelets infected.
H =over 80% spikelets infected.
M =40-80% spikelets infected.
L =10-40% spikelets infected.
T =1-10% spikelets infected.

† Neck and upper sheath of plants only inoculated.

‡ Average number of spikelets infected on four heads.

The 28 forms of *H. sativum* produced a brown to blackish discoloration on the glumes of wheat and barley. All caused embryo discoloration and local to general necrosis of the seed. In many cases the ovaries of the inoculated plants of both wheat and barley failed to develop. Barley spikes were frequently blighted completely in the flower or milk stage. In general, the controls remained free, or relatively free, from infection. In the latter cases the few diseased spikelets which developed were never so heavily infected as those which had been artificially inoculated. The organisms concerned were recovered repeatedly in pure culture from diseased spikelets of wheat and barley.

VARIATION IN PATHOGENICITY

From Table V it is evident that the degree of virulence is not correlated with the host or part of host from which the fungus was isolated. For instance, Forms 27 and 37 were both isolated from the kernels and Forms 2 and 3 from the leaves of barley, yet they show marked differences in pathogenicity on barley. Form 5 was isolated from a node of wheat and is one of the most virulent root-rotting forms of both wheat and barley.

By consulting Tables XI, XII, and XIV, profound differences are noted in the pathogenicity, not only of forms obtained from widely separated localities, but also between forms occurring in the same locality. Eleven distinct forms differing greatly in pathogenicity on wheat and barley were isolated from plants grown on a small plot of land at University Farm, St. Paul, Minn.

COMPARATIVE VIRULENCE OF *H. sativum* AND OTHER ROOT-ROTTING ORGANISMS

Comparative tests on the pathogenicity of several root-rotting organisms were made on Marquis and Mindum wheats in the greenhouse. The results are given in Table XV. They were obtained in a manner similar to that described for the experiment summarized in Table XI. It is obvious that one can either prove or disprove the assertion that *H. sativum* is a more virulent root parasite than *Gibberella saubinetii* (Durieu and Mont.) Sacc., or *Fusarium spp.* (Table XV). For example, if *G. saubinetii* is compared with *H. sativum,* Form 1, the difference in virulence is negligible, but *Gibberella* is much more virulent than Form 21. However, the opposite appears to be true if *Gibberella* is compared with Form 8 (Plate VI). No general statement can yet be considered final on this subject, because strains of *G. saubinetii* apparently also vary greatly in their degree of virulence; and many different *Fusaria* attack the roots of cereals. Furthermore, one must know the behavior of these organisms under various ecological conditions before any general conclusion can be made regarding their relative degrees of virulence.

TABLE XV

RESULTS OF GROWING MARQUIS AND MINDUM WHEATS IN SOIL INOCULATED WITH DIFFERENT FUNGI

Organism	Percentage of seeds which produced seedlings										No. of plants which survived	
	Marquis					Mindum						
	Pot No.					Pot No.						
	1	2	3	4	Av.	1	2	3	4	Av.	Marquis	Mindum
Control	88	84	80	92	86	88	84	80	80	83	86	83
Gibberella saubinetii	48	44	40	52	46	44	40	24	28	34	19	6
Fusarium sp. (from corn)	24	36	16	32	27	24	32	12	4	18	24	16
Fusarium moniliforme	80	68	76	88	76	68	64	68	68	67	76	67
H. sativum (Form 8)	8	0	0	4	3	0	0	8	0	2	2	2
H. sativum (Form 1)	20	28	28	24	25	16	20	24	36	24	4	10
H. sativum (Form 21)	36	40	60	56	48	76	52	52	72	64	45	59

Our knowledge concerning the relative parasitic activities of these root-rotting organisms is limited to a few known strains or forms, and does not extend to the groups as a whole. Moreover, varietal resistance is a significant factor and must be taken into consideration.

STABILITY OF THE PHYSIOLOGIC FORMS

The range of variability of *H. sativum* is very wide. The character and rate of growth, the ability to reproduce, and the morphology of the organism are influenced profoundly by the kind, proportion, and amount of food available, and by other environmental conditions. Dosdall and Christensen (25), Stevens (62), and others have demonstrated this conclusively. Besides, it has been shown that there are many forms of *H. sativum* which respond differently to various environmental conditions (18 and 19).

Temporary phenotypes, or ecads, induced by differences in environmental conditions, occur frequently, altho the genotype remains unaltered. Such variants revert to the parental phenotype as soon as the causal stimulus is removed. Comparative cultural tests carried on for several years indicate that some forms of *H. sativum* remain constant and always appear the same under identical conditions. The question then arises: How did the forms originate, and are they relatively stable? New forms of life are generally supposed to arise as a result of hybridization or mutation.

POSSIBILITY OF HYBRIDIZATION

Hybridization is, of course, common in higher plants. There is some evidence that it also occurs quite frequently in fungi. Hybridization may take place at two different stages in the life cycle of fungi: (1) by the fusion of plus and minus strains, (2) by the anastomosing of vegetative hyphae.

Plus and minus strains occur in all four classes of fungi (6, 15, 21, 23, and 28). According to Blakeslee (6), Saito and Naganiski reported true hybrid zygospores between different species of *Mucor;* and Burgeff crossed a distinct mutant from a *Phycomyces sp.* with the original stock. Blakeslee (6) secured zygospore formation between many similar strains of *Mucor,* and between some which were quite different. The same author (6) observed what he terms "imperfect hybridization" between opposite sexes of different species of *Mucor,* and between sexes belonging to different genera.

Dodge (23) has demonstrated the presence of sexual strains in the genus *Ascobolus.* Buller (15) believes that there are at least four sexes in some of the *Hymenomycetes.* Blakeslee (6) found in all the hermaphroditic species of Mucorales investigated that all the spores in a "germ sporangium" were hermaphroditic. In the dioecious species there were two types of zygospore germination. The spores in the germ sporangium of *Mucor mucedo* were all of the same sex—plus or minus, never mixed. In the genus *Phycomyces* the germ sporangium may contain spores of both sexes. Thus, in *Mucor mucedo* sexual differentiation occurs when or before the zygospores germinate; in *Phycomyces,* in the germ sporangium. He states that induced growths from a germ tube of a sporangium in *Phycomyces* gave rise temporarily to a hermaphroditic plant. Such a plant differed strikingly from the normal plus and minus parent plants. According to Blakeslee (6), Burgeff has produced hermaphroditic strains of *Phycomyces* by mechanically mixing the protoplasm of plus and minus vegetative filaments.

Brierley (11) pointed out the possibility of genetic contamination in fungi by the fusion of hyphal cells without the intervention of the sexual stage. Stevens (62), Dosdall (24), Ocfemia (52), and Drechsler (26) have observed the anastomosing of germ tubes and hyphae of various species of *Helminthosporium.* The writer has observed the lateral fusion of as many as seven germ tubes of *H. sativum* in one series.

Matsumota (48) has observed fusion between the hyphae of different strains of *Rhizoctonia solani* Kühn. Brierley (11) recorded similar observations for *Botrytis cinerea* Pers. Ezekiel (29) observed that hyphal anastomosis took place in agar plates at the junction of colonies of similar strains of Sclerotinia, as well as between different species of this genus.

However, colonies of different forms of *H. sativum,* and even of the same form, usually do not fuse, because they are antibiotic to each other (Plate I, Fig. 2). Many plates were inoculated with different species of *Helminthosporium,* and with distinct forms of *H. sativum;* but, in every case only the parental types appeared. However, too

much importance should not be attached to this preliminary test. Each cell contains a variable number of nuclei from one to four (62), and there are therefore many chances for normal or abnormal rearrangement of chromosomes or complete nuclei.

MUTATION

Recent publications (7, 9, and 62) indicate that asexual mutations in fungi occur frequently on culture media. Mutations have been reported for fungi belonging to the *Phycomycetes, Ascomycetes,* and *Fungi imperfecti.* In 1922, Stevens (62) presented evidence that mutations were common in *Helminthosporium* growing in culture. In the present studies, much of Stevens' work was repeated and extended; and, in general, the results were corroborated.

Numerous and widely different types of mutants, usually occurring in sectors, have been observed repeatedly. These variations arose from parts of mycelium and were generally wedge-shaped or fan-shaped (Plates VII and VIII). Under certain conditions mass-like mutation apparently occurred in some forms. This type of mutation has recently been described in higher plants also (12).

In the present work numerous transfers were made from sectors and normal parent material. When the original variant was chosen from a sharply defined sector of a relatively young culture, as illustrated in Plate VII, it always developed into a colony distinct from its parent. Furthermore, a study of subsequent transfers from these sectors indicated that the changes were genotypic and not mere changes in phenotypes due to environmental conditions. Single-spore isolations, whether from the sector in which a variant originated, or from colonies developed from mass transfers, grew similarly on culture media. In either case the colonies were all alike. Mutants bred true when propagated from spores or mycelium. Stevens (62), Burger (16), and others also have demonstrated that spores from mutants again produced the mutant type.

In order to ascertain whether there were any differences in the tendency of various forms to mutate, two kinds of media were inoculated. Each form was grown in triplicate plates of uniform size, containing 18 cc. of the medium. The plates for each series were inoculated on the same date, and kept on the same table in the laboratory. Notes on the number of sectors were taken on the 11th and 15th days after inoculation. As time would not permit the culturing and studying in detail of all these variations, the term sector is often used in the following discussion whenever the corresponding breeding test was not made. Table XVI summarizes the results of the experiment.

TABLE XVI

NUMBER OF SECTORS, OR APPARENT MUTATIONS PRODUCED BY 37 PHYSIOLOGIC FORMS OF *H. sativum* ON POTATO DEXTROSE AGAR AND OATMEAL-RICE-CORNMEAL AGAR

Form No.	Potato dextrose agar				Oatmeal-rice-cornmeal agar			
	Age, 11 days		Age, 15 days		Age, 11 days		Age, 15 days	
	No. of plates with sectors	Total No. of sectors	No. of plates with sectors	Total No. of sectors	No. of plates with sectors	Total No. of sectors	No. of plates with sectors	Total No. of sectors
1	1	1	2	3	1	1	1	2
2	0	0	0	0	2	3	2	5
3	3	5	3	8	2	3	3	8
4	0	0	3	3	0	0	2	5
5	0	0	0	0	0	0	2	6
6	2	7	2	8	0	0	2	3
7	0	0	0	0	0	0	0	0
8	1	3	1	4	1	1	3	3
9	2	2	2	3	3	5	3	16
10	0	0	0	0	1	1	2	2
11	1	1	1	1	2	2	2	2
12	0	0	0	0	0	0	0	0
13	0	0	0	0	1	1	1	1
14	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0
16	1	1	1	1	3	8	3	8
17	1	1	1	2	3	7	3	9
18	0	0	0	0	1	1	1	2
19	0	0	0	0	1	1	2	4
20	1	1	2	2	3	10	3	15
21	0	0	0	0	0	0	0	0
22	1	3	2	8	0	0	1	1
23	0	0	0	0	0	0	0	0
24	0	0	0	0	1	1	1	1
25	0	0	0	0	1	1	1	1
26	2	2	2	2	0	0	0	0
27	0	0	0	0	0	0	0	0
28	1	1	1	1	2	2	2	3
29	1	3	1	3	0	0	0	0
30	2	5	2	5	3	5	3	13
31	0	0	0	0	3	7	3	8
32	0	0	0	0	0	0	2	4
33	0	0	0	0	3	19	3	36
34	2	2	2	4	3	3	3	3
35	0	0	0	0	1	4	1	4
36	2	3	2	3	3	8	3	15
37	1	1	1	1	0	0	0	0

It is evident that some forms mutate more often than others. Mutations occurred in forms obtained from England, Australia, Africa, Argentina, Serbia, and Canada and from various localities in the United States.

The data in Table XVI also show that a given form may mutate more frequently on one nutrient medium than on another. On potato dextrose agar 18 out of 37 forms developed sectors, while on oatmeal-rice-cornmeal agar sectors occurred in cultures of 27 of the 37 forms. Seven forms failed to develop sectors on either medium. Forms 26, 29, and 37 gave rise to apparent mutations on potato dextrose agar,

but not on the other medium. Twelve of the forms which did not mutate on potato dextrose agar did so on the oatmeal-rice-cornmeal agar. The difference in the number of sectors of certain forms on the two media sometimes was very marked. Thus, Form 33 developed 36; Form 30, 15; Form 16, 8 sectors on oatmeal-rice-cornmeal agar; but none, 5, and 1, respectively on potato dextrose agar.

Some of these mutants have been grown on several different media for varying lengths of time, but they have remained constant for the characters under observation. Mutants appeared as stable as the various forms of *H. sativum* which have been isolated from host tissue. Altho it is true that several mutants apparently reverted, these reversions were always in the form of a sector. This agrees with the observations of Stevens (62). Temporary modifications are not considered here. They sometimes appear, especially in old cultures, but they revert to the parental type on the first transfer.

Some of the mutants which were cultured mutated still further. Colonies of a mutant have been observed to produce distinct sectors which in turn mutated while still in the same plate. Two of the mutants gave rise constantly to new mutants, their behavior suggesting that they might be segregating heterozygotes.

Roberts (54) observed two variants, "A" and "B", in the progeny of a single conidium of *Alternaria mali* Roberts derived from a succession of 15 singly selected conidia. For the first 10 selections, variant "A" had a slight tendency to break up into "A" and "B"; but from then on it remained constant. Variant "B" broke up into "A" and "B" sectors for 57 selections, but thenceforward it grew true to type. Stevens (62) observed that a number of *Helminthosporium* mutants were unstable and constantly gave rise to new variants.

The mutants, like the 37 forms of *H. sativum* previously mentioned, behave differently on different culture media. For instance, on a given medium a mutant sometimes resembles its parent very closely, but on a different medium it sometimes is so different culturally as to look like another species.

Altho Form 1 had been grown on hundreds of plates from the time it was isolated in the winter of 1919, no distinct sectors were ever observed until the winter of 1924-25. On the other hand, Form 3 was constantly mutating, especially on green bean agar. While determining the effect of various amounts of nutrient media on zonation, it was repeatedly observed that colonies of Form 1 growing in petri dishes containing 10 cc. and 15 cc. of oatmeal-rice-cornmeal agar produced numerous sectors. At the same time and under similar conditions, none appeared in dishes containing 20 and 30 cc. of medium. The history of Form 1 is shown diagrammatically in Figure 1.

Colonies which gave rise to mutations in the petri dishes marked 1 to 11 in Figure 1 were all started from mass transfers. Twenty single-spore isolations were made from the same tube. Ten of the spores were used in inoculating 10 plates, each containing 30 cc. of green bean agar, and 10 for the same number of oatmeal-rice-cornmeal agar. Not a single sector appeared in the 20 plates inoculated with single spores; neither did any occur in the two controls. The 10 colonies on each medium derived from single spores, and the control, were all alike in general appearance in each case (Plate IX). This indicated the homozygosity of this form. La Rue (41) concluded that selection is totally ineffective in establishing distinct lines within a pure strain of *Pestalozzia guepini* Desm. However, in order to obtain additional evidence regarding variations by single-spore selection, the following experiment was made (Fig. 1).

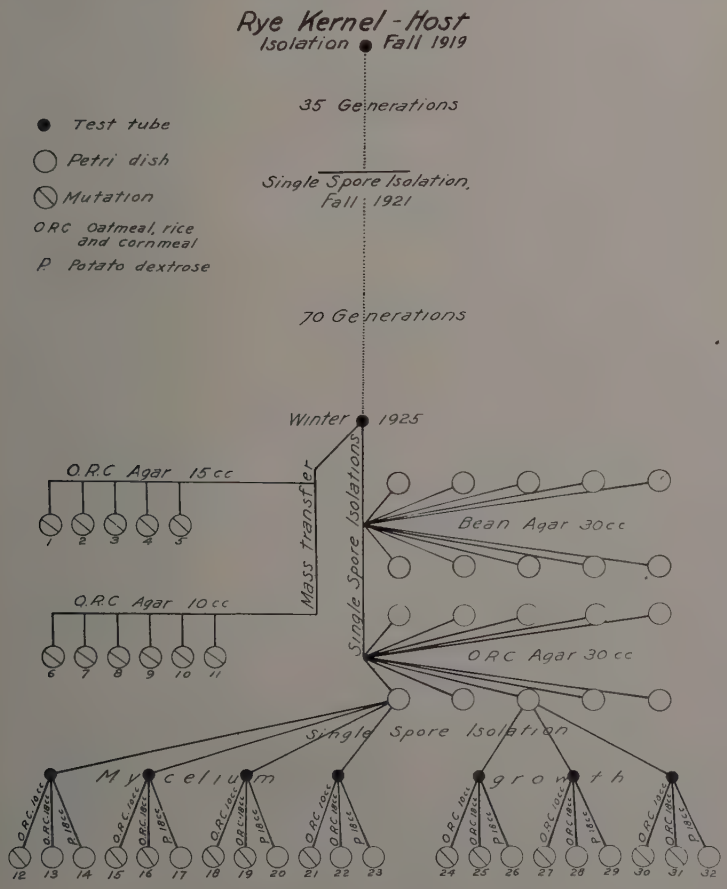


Fig. 1. Graphic Representation of the History of *H. sativum*, Form 1

Three and four single-spore isolations were made from each of two monosporous cultures which were previously derived from a culture of single-spore origin. The conidia were transferred to test tubes, and mycelium only had developed at the end of 4 days. From each of these tubes 3 plates were inoculated, one containing 18 cc. of potato dextrose, one 18 cc. of oatmeal-rice-cornmeal agar, and one 10 cc. of the latter medium. From Figure 1 it is apparent that mutations appeared in all plates with 10 cc. of agar, and in 4 of the 7 plates which contained 18 cc. of the combination agar. None whatever arose in the 7 plates containing potato dextrose agar.

In order to determine the effect of the amount of medium on the expression of variation, the following test was made. Newly poured agar plates were placed on a slight incline so that the upper side was covered with a thin layer of the medium, the lower by a considerably thicker layer. These slants were inoculated in the center in the usual manner. Numerous sectors developed, but only in the region of the thinner layer of agar (Plate VII, Fig 2). That some of these sectors were true mutants was proved by successive transfers.

Table XVI indicates that mutations may occur at different distances from the source of inoculation (Plates VII and VIII). Sectors have been observed to arise from near the center of the colony but, for the most part, the number of variants was greater near the edge.

Blakeslee (7) obtained mutants from a hermaphroditic fungus, *Mucor genevenis,* which apparently had their origin within the spore, or at least within the sporangium. In the present investigation there was no evidence that the differentiation which gave rise to mutation occurred in the spore. It will be seen from Figure 1 that colonies 1 to 11, obtained from mass inoculation, gave rise to 36 mutations. Colonies 12, 15, 18, 21, 24, 27, and 30 arose directly from the mycelial growth of a single spore, which in turn was derived from three successive single-spore transfers. They developed 38 apparent mutants. These results and similar results with Forms 22 and 24 indicate that mutations occur as frequently in cultures derived from single conidia as from colonies resulting from mass transfer of spores and mycelium.

The mutants studied varied from the parents in the following characters: (1) rate of growth, (2) nature of mycelial growth and whether cottony or felty, etc., (3) conidial production, (4) conidial clusters, (5) color, and (6) zonation. Many of the gross characters in some forms were quite different from any of those observed in strains or forms isolated from host plants. These mutants differed culturally from each other quite as much as do certain species of *Helminthosporium—H. teres* Sacc., *H. pedicellatum* Henry, and *H. gramineum* Rab. In general the variations observed were similar to those reported by Stevens (62).

Apparently most mutations in fungi have been due to the loss of a factor or group of factors for color, and of a factor for abundant fructification. Stevens (62) states that mutants with low conidial production, verging on sterility, coupled with paleness of colony, occurred with the greatest frequency. This is in accord with the writer's findings.

Several distinct types of mutants frequently occurred in the same plate, but usually a given form gave rise to one or two types only. A single colony has given rise to twelve similar mutants. Within a period of 6 months, however, Form 1 has thrown as many as seven distinct mutants which retained their distinctive characters after repeated transfers.

Just how these mutations arose is not known. They may have arisen through what might be termed normal nuclear rearrangement, or through aberrant chromosomal distribution, or gene changes. It has been impossible to determine accurately the genetic constitution of the parents and their mutants, because the nuclei and chromosomes are very small and the plants are propagated asexually, thus rendering cross-breeding experiments futile. Even if a variant resulted from the fusion of two adjoining cells, it might not necessarily be considered a normal process of combination or segregation, as it has been shown that anastomosing of hyphae is an extremely common phenomenon in *H. sativum.*

From Figure 1 it is apparent that mutations were not observed in *H. sativum,* Form 1, until after it had grown in culture for 6 years, during which time it went through more than 100 "generations." Form 3, on the other hand, from the time it was isolated four years ago, has had a conspicuous tendency to mutate, especially on green bean agar. The sexual stage of *H. sativum* has never been reported. Many and varied attempts to produce it in culture have given only negative results. Apparently the recent intervention of a sexual stage is not essential for mutation in those fungi which can propagate sexually.

Several investigators have tried to induce mutation by environmental changes. According to Brierley (10 and 11), Arcichovskij, Waterman, and Schiemann have described mutation in *Aspergillus niger* and *Penicillium glaucum.* These authors claim to have induced mutation in these fungi by various environmental changes, such as the addition of zinc sulphate to the substrate, exposure to high temperatures, etc. Brierley (10) repeated much of their work but could not confirm it.

Stevens (62) unsuccessfully attempted to produce "saltations" by artificially wounding, by mixed planting, and by implanting.

PATHOGENICITY OF MUTANTS COMPARED WITH THAT OF THEIR PARENTS

In order to ascertain whether there are any differences between the degrees of virulence of mutants and their parents, comparative tests were made on Trebi barley and Marquis wheat. The experiment was similar to that already described for testing the pathogenicity of the 37 forms of *H. sativum* on barley, except that six pots of each cereal were used. The virulence of 13 mutants was compared to that of their parents. Notes were taken on the percentage of plants that emerged, on the percentage of plants with deformed primary leaves, and on the degree of stunting. The results are presented in Table XVII.

TABLE XVII

RESULTS OF INOCULATING SOIL GROWING TREBI BARLEY AND MARQUIS WHEAT, WITH 4 PHYSIOLOGIC FORMS AND MUTANTS OF *H. sativum*

Organisms	Wheat			Barley		
	Percentage			Percentage		
	Seeds developing into seedlings*	Infected and deformed primary leaves	Virulence in comparison to parent†	Seeds developing into seedlings	Infected and deformed primary leaves	Virulence in comparsion to parent
Form 1						
Parent	76	22.7		88	17.3	
Parent S_3‡	73	21.9	Same	86	23.3	Same
Mutant 1	76	35.0	Greater	81	72.3	Greater
" 3	86	15.5	Same	89	11.2	Same
" 4	85	7.8	do	81	9.8	do
" 5	83	23.2	do	88	19.0	do
" 6	78	23.0	do	84	23.0	do
" 21	90	0.0	Less	84	3.5	Less
" 22	90	3.7	do	88	4.5	do
" 25	73	23.2	Same	86	24.0	Same
Form 8						
Parent	28	85.7		70	90.0	
Mutant 75	22	84.5	Same	68	98.0	Same
Form 22						
Parent	76	23.0		81	13.6	
Mutant 40	31	85.0	Decidedly greater	72	91.6	Decidedly greater
" 41	84	10.0	Same	88	6.1	Same
Form 24						
Parent	72	26.0		86	22.1	
Mutant 30	76	23.7	Same	84	26.0	Same
" 31	88	7.4	Less	81	5.7	Less

* Based on six pots of 25 seeds each.

† Based on percentage of plants that emerged, on percentage with deformed and infected primary leaves, and on general degree of stunting.

‡ Derived from three successive single-spore isolations.

The mutants did not all possess the same degree of virulence. Most of them were like the parent form, but two were decidedly more virulent than their respective parents. Mutant No. 40 was outstandingly more virulent than its parent, Form 22, on both barley and wheat (Plate X, Figs. 1 and 2). Three of the mutants and possibly more were less virulent than their parents. A decrease in virulence is harder

to detect than a change in the opposite direction, when the parents are relatively weak forms.

Mutant 40 was derived from a single spore from a monosporous culture of Form 22. It arose as a distinct sector, similar to the one shown in Plate VII, and had been transferred several times and grown on three different nutrient media. The cultural characteristics were not only different from those of its parents, but were unlike those of any of the forms under observation.

This mutation in virulence probably is going on continually in nature. It complicates the problem of controlling the disease and makes extreme caution necessary in drawing conclusions regarding the virulence of the pathogene. It probably means also that resistant varieties may be resistant only for a certain length of time and for certain localities. The duration of usefulness of resistant varieties probably is largely a matter of chance. Unusually virulent forms may arise by mutation. In this case the resistant varieties may become susceptible. On the other hand, it should be remembered that some of the mutants are less virulent than the parents. It is even possible that these weakly parasitic mutants might be eliminated in the struggle for existence.

It is especially interesting to note that physiologic forms of all pathogenic fungi do not necessarily behave alike. The physiologic forms of the stem rust fungi appear to be quite stable. There is considerable evidence that they do not mutate commonly, and that hybridization, if it occurs at all, is relatively infrequent (53, 58, and 59). But the physiologic forms of *H. sativum* are quite different in this respect. Some of them are very stable while others are extremely unstable. It is obvious that one can not generalize too much about physiologic specialization. General statements about the pathogenicity of a pathogene mean little without a knowledge of the number, distribution, and parasitic capabilities of different physiologic forms.

FORMATION AND GERMINATION OF SPORES

EFFECT OF ENVIRONMENTAL FACTORS ON FRUCTIFICATION

During the last four years the writer has made numerous attempts to induce *H. sativum* to produce an ascigerous stage. Infected seed of wheat and barley, heads of wheat, seedlings and cultures of the fungus were placed outdoors during the winter. Some of this material was buried in the ground at different depths; some was left in the pots in which it was grown. No perithecia developed. Cultures of the organisms were grown on different nutrient media and subjected to different conditions of temperature, moisture, and light, but only the

conidial stage developed. Starvation and the addition of toxic compounds proved fruitless. The pathogene was cultured on more than 100 different culture media and plant tissues, but all attempts to induce perithecial formation were unsuccessful. More than 70 strains, including many physiologic forms, were grown for years on culture media and on wheat heads, but no indication of the sexual stage was ever observed. Many mixed cultures of different physiologic forms were grown on wheat heads and on different nutrient agars, but they produced asexual spores only.

Many forms of *H. sativum* produced conidia freely on various plant tissues and on artificial media, while others apparently seldom fructified on culture media. Chlamydospore-like structures formed frequently within a liquid substrate. An abundance of spores was produced on a 2 per cent sucrose solution. The organism also fructified on diseased plant parts beneath the surface of the sandy soil. On sterilized soil to which organic material was added, certain forms sporulated profusely, and others grew well but developed no spores. In some seasons the pathogene sporulated freely on the above-ground parts of the host plants.

The results, showing the effect of light and temperature on the production of conidia by Form 1, are summarized in Table XVIII. It seems safe to conclude that the production of conidia is influenced greatly by temperature, but not appreciably by light.

TABLE XVIII

Relation of Temperature and Light to Formation of Conidia by *H. sativum*, Form 1, on Potato Dextrose Agar

Temperature, degrees C.	Light relation	Days required for fructification	Conidial production
5-7	Dark	?	None
10-12	do	10	Trace to light
16-17	do	3	Abundant
20-21	do	3	do
20-21	Alternation (lamplight)	3	do
20-30 (changed every 12 hrs.)	Dark	3	do
24-25	do	3	do
29-30	do	3	Trace
32-33	do	?	None
Outdoors	Diurnal changes	3	Abundant
Greenhouse	do	3	do
Buried in soil	Dark	?	do
20-22	Continuous light	?	do

The optimum temperature for the production of conidia by Form 1 seems to be between 16° and 25° C. Changes within these limits have little effect. The maximum appears to be about 29° C. At any rate, temperatures of 29° C. or higher partly inhibit spore formation. The minimum temperature at which spores are formed seems to be from

10° to 12° C. Only a few were produced at this temperature, and none were produced at a temperature of from 5° to 7° C. Here again, however, it is important to remember that the different physiologic forms may react differently to temperature. In fact, there is direct evidence of this fact. Dosdall (24) observed that *H. sativum*, strain 82A (the writer's Form 2), sporulated well at 32° C. At this temperature Form 1 grew scarcely at all, and produced no spores.

The time required for the production of spores varies somewhat with the conditions. On a few occasions conidia germinated and produced spores within 24 hours. Conidia were produced within this time from spores sown in syracuse dishes containing 0.5 cc. of water and bits of host tissue. Usually, however, 48 hours or longer was required. Mycelium on diseased tissue sporulated in from 12 to 24 hours. Unboiled polished rice, kept moist, was covered with a dense mass of spores 3 days after it had been inoculated with conidia of *H. sativum*.

The same mycelium may produce more than one crop of spores. This was demonstrated by growing the organism on a solid substratum and scraping off the entire crop of conidia after the mycelium had sporulated abundantly. Within 3 or 4 days a new crop of conidia had been produced. It is quite probable that several successive crops of spores are produced in nature. The fact that abundant conidia can be formed within a comparatively short time is very significant in evaluating the parasitic capabilities of the fungus.

EXPERIMENTS ON ATTENUATION

Attenuation of virulence of fungi after continued culturing on artificial media has been reported occasionally. Mitra (49) stated that *H. turcicum* Pass. lost its parasitic nature if cultivated for a long time in culture. Inoculation with a strain kept in culture a year failed to produce infection. Krakover (40) reported attenuation in virulence for *Macrosporium sarcinaeformis* Cav. from red clover. Bonar (9) stated that long continued growth on culture media of *Brachysporium trifolii* Kauff. caused an attenuation of its virulence.

Six years of culturing on artificial media, mostly on potato dextrose agar, did not change the virulence of *H. sativum*, Form 1. After 3 years of dormancy, Form 4 was again transferred to culture media. Its pathogenic capabilities were not altered. Most of the virulent forms of *H. sativum* here reported have been cultured for 3 or 4 years on various cultural media. Even if a change in pathogenicity should occur over several years, it could more plausibly be explained by mutation than by attenuation due to culturing. Stevens (62) reported apparent mutation of *Helminthosporium spp.* in test-tube cultures. The writer

obtained some evidence that mutation occurred also in test-tube cultures of *H. sativum*, notably in Forms 7 and 23. Single-spore isolations from these two forms, developed on potato dextrose agar, did not sporulate when sown on the same medium.

SPORE GERMINATION

The process of spore germination in *H. sativum* and some of the factors influencing it have been described by Dosdall (24). She found that spores of culture "82 A" (Form 2) germinated in redistilled water equally well at temperatures ranging from 6° to 39° C. The optimum, based on length of germ tube and time required for emerging, was between 22° and 30° C. Spores germinated at hydrogen-ion concentrations of pH 2.4 to pH 12. These facts show that the conidia germinate under a wide range of conditions.

However, the results obtained by the writer indicate that spore germination may be influenced profoundly by slight changes in environment. Relatively few spores germinated in the early tests, hence a study was made to determine the most important factors affecting germination.

EFFECT OF PLANT TISSUES

Several investigators have observed that the presence of host tissue affects spore germination of various pathogenes. Anderson (2) showed it for pycnidiospores of *Endothia parasitica* (Mur.) Anders.; Brown (13) for conidia of *Botrytis cinerea* Pers.; Leach (42) for spores of *Colletotrichum lindemuthianum* (Sacc. and Mag.) Bri. and Cav.; Noble (51) for spores of *Urocystis tritici* Koern.; and Whitehead (67) for spores of *Urocystis cepulae* Frost.

The effect of host tissue on spore germination of *H. sativum* was tested by placing conidia in syracuse dishes containing from 0.5 to 1.0 cc. of distilled water. To these dishes from 10 to 20 small pieces (0.5 to 1.0 cm. long) of barley seedlings were added. The controls contained distilled water only. All tests were made in duplicate, usually at room temperature, and the percentage of germination was calculated from a count of 100 spores in each dish. In every case, unless otherwise indicated, spores of Form 1 grown on sterilized wheat heads were used. Some of them had been stored for varying periods of time outdoors or in the laboratory. Those which were kept outside had been wrapped in small cheesecloth packets and buried just below the surface of the ground.

The spores germinated best and most uniformly in the dishes containing host tissue (Table XIX). The greater fluctuation in the series from outdoors was probably due to the presence of some toxic substance in the sand or soil. Table XIX does not give an adequate idea of the stimulatory effect of plant tissue. Within 24 hours nearly all

spores germinating in dishes containing host tissue had developed long, very much branched, and vigorous germ tubes, often extending across the low-power field of the microscope. In sharpe contrast, spores germinating in containers without host tissue usually produced relatively weak, short, unbranched germ tubes. Furthermore, the spores in dishes containing host tissue almost always germinated from both ends, while those in the control dishes frequently germinated from one end only.

TABLE XIX

GERMINATION OF SPORES OF *H. sativum*, FORM 1, IN DISTILLED WATER WITH AND WITHOUT THE ADDITION OF BARLEY LEAF TISSUE

Time of exposure, days	Percentage of germination											
	Laboratory						Outdoors					
	Distilled water			Distilled water with tissue			Distilled water			Distilled water with tissue		
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.
125	22	25	23.5	96	94	95.0	4	1	2.5	98	90	94.0
155	36	76	56.0	97	98	97.5	0	1	0.5	96	95	95.5
186	95	77	86.0	99	99	99.0	82	87	84.5	99	98	98.5
209	30	10	20.0	99	99	99.0	1	0	0.5	90	70	80.0
242	..	..	...	..	..	...	82	94	88.0	94	96	95.0
310	70	65	67.5	96	98	97.0	11	7	9.0	83	96	89.5

It was observed also that in the controls there was a higher percentage of germination of spores floating on the surface than of those which were submerged. This is in accord with Dosdall's results (24). On the other hand, no differences could be detected in percentage of germination of submerged spores or those on the surface when host tissue was added. Preliminary tests indicated that newly-formed spores germinate more freely under water in the absence of host tissue than do more mature spores. There is some evidence, also, that the substratum on which the spores are produced affects the percentage of spores that germinate in distilled water. This may possibly account for the high percentage of germination observed by Dosdall (24). But, even under the most favorable conditions, the maxmium germination in her experiments seldom exceeded 90 per cent. By the addition of host tissue, the writer consistently obtained from 95 to 100 per cent germination of spores which had been kept in the laboratory for varying periods of time.

Brown (14) found that certain plants produced volatile substances which stimulated spore germination of several fungi while substances from other plants were ineffective or actually deleterious. In his work on the germination of spores of *Colletotrichum lindemuthianum*, Leach (42) obtained some evidence that tissues of plants other than the host stimulated germination. Noble (51) showed definitely that

uninjured seedlings of non-susceptible plants (field peas, beans, rye) stimulated the germination of spores of *Urocystis tritici.*

The effect of various non-susceptible plant tissues on germination of conidia of *H. sativum,* Form 1, was determined (Table XX). Apparently the stimulatory agent is not specific. Wheat, oats, rye, bluegrass, strawberry, sunflower, tomato, and potato tuber tissues stimulated germination. But bits of very young potato sprouts inhibited the development of germ tubes, possibly because of the presence of the alkaloid solanin. Many of the spores in one syracuse dish containing tomato tissues failed to germinate normally, the germ tubes often emerging and then producing deformed branches. Leach (42) also noticed abnormal branching of the germ tubes of *C. lindemuthianum* when tissues of tomato and several other plants were added to the distilled water. Altho the percentage of germination of conidia of *H. sativum* was usually not reduced by the presence of tissues from non-susceptible plants, the vigor of the germ tubes was usually greater in the presence of tissues from susceptible plants.

TABLE XX

GERMINATION OF SPORES OF *H. sativum,* FORM 1, IN DISTILLED WATER, WITH AND WITHOUT THE ADDITION OF TISSUES OF VARIOUS PLANTS

Plant part	Percentage of germination			Degree of vigor of germ tubes
	Ser. A	Ser. B	Av.	
Barley (seedlings)	96	94	95.0	Very vigorous
Wheat do	97	95	96.0	do
Oats do	96	97	96.5	do
Rye do	94	94	94.0	do
Bluegrass (leaf)	98	96	97.0	Vigorous
Strawberry do	93	90	91.5	do
Sunflower do	92	97	94.5	do
Tomato do	97	94	95.5	Many very much distorted and failed to develop. Some tubes vigorous.
Potato tuber	94	96	95.0	Vigorous
Green potato shoots (1-2 cm. long)	65	83	74.0	Weak, less than 20 microns long and failed to develop
Control without tissue (spores 14 months old)	40	38	39.0	Weak
Without tissue (spores 1 month old)	46	55	50.5	do

Several tests were made in order to determine the effect of soil and manure extracts on spore germination (Table XXI). Only a few spores germinated in these extracts. In fact, they seemed to be toxic, but the addition of host tissue counteracted their toxic effects to a considerable extent. Boiling apparently destroyed the toxic substance. As *H. sativum* is a common saprophyte in the soil, it is surprising that the spores germinate so poorly in soil and manure decoctions.

TABLE XXI

GERMINATION OF SPORES OF *H. sativum*, FORM 1, IN SOIL AND MANURE EXTRACTS WITH AND WITHOUT THE ADDITION OF HOST TISSUE

Material from which extract was made	Percentage of germination and vigor							
	Medium with host tissue				Medium without host tissue			
	Ser. A	Ser. B	Av.	Vigor	Ser. A	Ser. B	Av.	Vigor
Check, distilled water	99	99	99.0	Very vigorous	38	62	50.0	Fair
Boiled peat	91	98	94.5	Vigorous	13	24	18.5	Weak
Unboiled peat	70	97	83.5	do	19	15	17.0	do
Well-rotted manure..	96	88	92.0	Very vigorous	5	3	4.0	Very vigorous
Heavily manured soil	27	60	43.5	Weak	4	1	2.5	do
Boiled heavily manured soil	98	97	97.5	Very vigorous	80	50	65.0	Fair
Clay soil	45	76	60.5	Fair	31	9	20.0	Weak
Boiled clay soil.....	96	95	95.5	Vigorous	8	16	12.0	do
Greenhouse soil	96	98	97.0	Very vigorous	29	23	26.0	do
Sterilized greenhouse soil	98	98	98.0	do	15	11	13.0	do
Standing water (outside	90	96	93.0	do	17	13	15.0	do
Dirty snow water...	97	84	90.5	do	9	14	11.5	do

VITALITY OF CONIDIA

Other things being equal, any pathogene which produces large numbers of spores under a fairly wide range of conditions is much more likely to become widely disseminated and established than one which produces spores only with difficulty and under a rather narrow range of conditions.

But spore production alone does not insure the success of a pathogene. The spores must be disseminated and must be able to withstand unfavorable conditions. Nor must they germinate too readily. If they do, it is likely that they may often germinate when there is nothing available for them to infect.

The results of the writer's studies on the vitality and germination of spores indicate clearly that the pathogene is well fortified against adversity. The spores can withstand low as well as high temperatures, provided the relative humidity is favorable. Furthermore, they can withstand long periods of alternate freezing and thawing. They can even remain in water for a year or longer without germinating. When host tissue is added to the water, however, the spores germinate promptly. This suggests the possibility that the spores germinate most readily in nature only in contact with host tissues.

The combined effect of various temperatures and relative humidities on the viability of conidia was tested. Spores were stored at relative humidities of 7.1, 30.7, 45.7, 73.4, 87.7, and 95 to 100 per cent at 6°, 12°, 24° and 29° C. The relative humidities, except the last one, were maintained in wide-mouthed bottles of 100-cc. capacity containing 50 cc. of saturated solutions of lithium chloride, sodium hydroxide, copper

nitrate, sodium chloride, and potassium sulphate, respectively, as suggested by Peterson (34). The 95 to 100 per cent humidity was obtained by using distilled water. Small paraffined cardboard baskets containing the spores were attached to the stoppers in such a manner than when the stoppers were replaced the baskets hung slightly above the surface of the liquids. The conidia used were grown on sterilized wheat heads in a single large Erlenmeyer flask. The corks were inserted tightly and covered with a coating of melted paraffin. Germination tests were made at the end of 82 days. The results are given in Table XXII.

TABLE XXII

EFFECTS OF TEMPERATURE AND HUMIDITY ON THE LONGEVITY OF CONIDIA OF *H. sativum*, FORM 1*

Storage temperature	Percentage of relative humidity	Percentage of germination			Vigor
		Ser. A	Ser. B	Av.	
5°- 7° C.	7.0+	99	100	99.5	Very vigorous
"	30.0+	90	94	92.0	do
"	45.7	100	98	99.0	do
"	73.4	98	98	98.0	do
"	89.7	99	96	97.5	do
"	90.0+	99	100	99.5	do
10°-12° C.	7.0+	97	90	93.5	do
"	30.0+	88	89	88.5	do
"	45.7	84	81	82.5	do
"	73.4	98	93	95.5	do
"	89.7	98	99	98.5	do
"	90.0+	97	99	98.0	do
24°-25° C.	7.0+	100	94	96.0	do
"	30.0+	99	93	96.0	do
"	45.7	0†	0†	...	
"	73.4	100	98	99.0	Very vigorous
"	89.7	10‡	15	12.5	Fair
"	90.0+	30‡	34	32.0	do
29°-30° C.	7.0	91	93	92.0	Very vigorous
"	30.0	89	96	92.5	do
"	45.0	†	..	...	
"	73.0	0	0	0	
"	90.0+	0	0	0	

* Experiment begun December 12, 1924.
† Spores discolored and killed by chemical in jar.
‡ Covered by growth of molds.

It is evident from Table XXII that humidity has a greater effect on viability than has temperature. Spores remained viable at low relative humidities (7 and 30 per cent) for a long time at the higher as well as at the lower temperatures. But at the higher temperatures high relative humidity was deleterious. At the higher temperatures toxic fumes were given off by the copper nitrate, so the results at a relative humidity of 45.7 per cent are not reliable.

The results of exposing spores and mycelium and seed infected with mycelium to high temperatures are presented in Table XXIII. Exposure for 10 minutes at 54° C. killed spores and mycelium in water, but

did not kill the mycelium in the seed. Similar results were obtained by soaking barley seeds in water at 52° C. for 15 minutes. The results in Table XXIII indicate also that a long-time immersion in water at 46° to 48° C. is more effective than a short immersion at 50° to 52° C. It is apparent that the standard hot-water treatments will not kill all of the mycelium in the seed of wheat and barley.

TABLE XXIII

RESISTANCE OF SPORES AND MYCELIUM OF *H. sativum*, FORM 1, AND OF THE MYCELIUM IN INFECTED KERNELS OF PENTAD WHEAT TO HOT WATER AT THREE DIFFERENT TEMPERATURES

Treatment	Material treated		
	Spores	Mycelium	Infected wheat
46°-48° C. for 2 hours	Few spores germinated, germ tubes weak	Required 5 days incubation before growth became visible	4 colonies developed from 20 seeds
50°-52° C. for 17 minutes	About 5 per cent of spores germinated, germ tubes weak	Not killed	4 colonies developed from 20 seeds
54° C. for 10 minutes	No germination	No growth	2 colonies developed from 20 seeds
Control	99 per cent germination	Rapid growth	16 colonies developed from 20 seeds

Preliminary tests were made on the effect of alternately freezing and thawing spores submerged in water. During the winter, syracuse dishes containing from 1 to 2 cc. of a suspension of spores in water were placed outside on the north side of the building. From time to time the dishes were taken into the laboratory, and after the ice had melted they were again placed outside. Sometimes the rise or fall in temperature was as much as 40° C. in a few minutes. Germination tests were made at the end of 6 weeks. In one lot, 50 per cent of the spores germinated. Spores on moist wheat kernels subjected to similar conditions germinated profusely. Eventually, after several months of this treatment, the spores were killed, but it is clear that spores can withstand alternate freezing and thawing for considerable periods of time.

To test further the effect of exposure on the vitality of conidia, spore material was grown on sterilized wheat heads which were wrapped in pieces of cheesecloth containing a handful of white sand, and buried outdoors just beneath the surface of the soil. In 1923 tests were made from material kept at University Farm; and in 1924 from material kept also at Northfield, Minn. Germination tests were made every month. Table XXIV summarizes the results.

TABLE XXIV

PERCENTAGE OF GERMINATION OF CONIDIA OF *H. sativum*, FORM 1, AFTER HAVING BEEN BURIED ONE INCH DEEP IN SOIL FOR DIFFERENT PERIODS OF TIME IN 1923, 1924, AND 1925

Date of test	University Farm, 1923-24*					
	Outside			Control‡		
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.
Oct. 4-5	..	..	..	96	98	97
Nov. 7-8	94	96	95	94	97	95.5
Dec. 7-8	93	97	95	..	..	..
Jan. 8-10	97	96	96.5	..	..	..
Feb. 13-14	98	90	94	95	96	95.5
Mar. 9-11	96	95	95.5	97	98	97.5
Apr. 10-11	99	98	98.5	99	99	99
May 7-8	90	70	80	99	99	99
June 12-13	94	96	95	..	..	..
July 16-18	94	82	88	..	..	..
Aug. 19-21	83	96	89.5§	96	98	97
Sept. 15-17	77	52	64.5	98	94	96

Date of test	University Farm, 1924-25†		
	Outside		
	Ser. A	Ser. B	Av.
Dec. 4-5	55	33	44
Jan. 7-9	91	90	90.5
Feb. 4-5	78	30	54
Mar. 4-5	6	12	9
Apr.	42	54	38

Date of test	Northfield, 1924-25†		
	Outside		
	Ser. A	Ser. B	Av.
	..	..	..
Nov. 14-16	63	65	64
Dec. 8-9	3	7	5
Jan. 13-15	11	7	9
Feb. 10-12	8	11	9.5
Mar. 15-16	10	12	11

* Put out Oct. 4, 1923.

† Put out Oct. 2 at University Farm and Oct. 5 at Northfield.

‡ Kept in laboratory.

§ Put out Dec. 15, 1923.

Spores exposed outside in October and December, 1923, at University Farm, withstood repeated changes in temperature and humidity, and endured alternate thawing and freezing without appreciable reduction in the percentage of germination until 9 months had elapsed. The results in 1924-25 do not agree with those of the previous year. This might be due to the ecological conditions under which the spores were produced, or it might be due to variation in meteorological conditions. The results indicate the importance of making such tests for more than one year. They also show the marked variation that may be expected in different lots of spores.

That aeration is an important factor in prolonging the life of conidia was demonstrated by the following experiment. Sterilized wheat heads and tubes of potato dextrose were inoculated with *H. sativum*. One series was plugged with cotton only, one was plugged with cotton and capped with tinfoil, and another was sealed with paraffin. These cultures were then put in various places, as indicated in Table XXV. Another lot of spores was produced on sterile wheat heads in a large Erlenmeyer flask and then placed in test tubes. One series was sealed with paraffin, the other, plugged with cotton, was used as a control. A study of the results shows that lack of aeration was more detrimental to spores under the conditions of the experiment than were light and temperature. The writer did not determine whether this deleterious effect was due to lack of oxygen or to production of volatile toxic substances by the organism. The relative humidity might have had some effect, but the results tabulated in Table XXI render this supposition doubtful. It will be remembered that a high percentage of spores germinated at 10° to 12° C. after storage at all relative humidities.

McKinney (47), in 1923, observed that spores of *H. sativum* did not germinate well in large quantities of water. He observed that spores kept in water from April to November germinated well, but toward the end of that period their vitality appeared pretty well exhausted. This is in accord with the writer's results, except that in one lot of spores no apparent decrease in percentage of germination was observed after the spores had been in unsterilized tap water for a year. The results of keeping spores in water are given in Tables XXVI and XXVII.

Spores did not readily lose their viability when kept in distilled water. There were some indications that small amounts of host tissue added to similar quantities of water rapidly reduced the viability of the spores. The reason for this decline is not definitely known, but the water in the containers soon became covered with molds, bacteria, and yeasts. It is quite likely that these organisms inhibited germination.

TABLE XXV

EFFECT OF AERATION ON LONGEVITY OF CONIDIA OF *H. sativum* WHEN PRODUCED AND STORED UNDER VARIOUS CONDITIONS

Place of storage and temperature	Time of exposure, days	Percentage of germination*					
		Wheat heads					Potato dextrose agar
		Tubes plugged with cotton†	Tubes capped with tinfoil†	Tubes sealed with paraffin†	Tubes plugged with cotton‡	Tubes sealed with paraffin‡	Tubes sealed with paraffin†
5°- 7° C. Dark.....	82	No spores	Few spores	No spores	97.5	94.0	No spores
6°- 9° C. Dark.....	139	...	96.5	...	...	...	...
10°-12° C. Dark.....	82	99.5	68.0	No spores	6.0	98.5	No growths
12°-14° C. Dark.....	129	...	0.0	...	...	...	...
Laboratory Light.....	82	96.5	69.0	0.0	0.0	98.0	No spores
do	139	...	Trace	...	...	...	...
24°-25° C. Dark.....	82	91.0	98.0	0.0	0.0	76.0	Trace
do	139	...	Trace	...	...	...	...
29°-30° C. Dark.....	82	No spores	No spores	No spores	0.0	72.0	No spores
do	139	...	No spores	...	...	...	...
Greenhouse Light	82	98.0	93.0	0.0	0.0	...	0.0
Windowsill (south side of building).....	139	...	0.0				
Windowsill (north side of building).....	139	...	53.0				

* Percentage based on a count of 200 spores.

† Spores developed after tubes were sealed.

‡ Spores developed before tubes were sealed.

The data in Table XXVI also show that the syracuse dishes to which host tissue was added gave a more reliable index of spore germination than those without the host tissue.

TABLE XXVI

EFFECT ON GERMINATION OF ADDING HOST TISSUE TO WATER IN WHICH SPORES OF *H. sativum*, FORM 12, HAD REMAINED FOR DIFFERENT PERIODS OF TIME WITHOUT GERMINATING

	Percentage of germination and relative vigor							
	Tap water with host tissue				Tap water without host tissue			
Date of test*	Ser. A	Ser. B	Av.	Vigor	Ser. A	Ser. B	Av.	Vigor
1924								
April 9-10	82	72	77.0	Very vigorous	3	2	2.5	Weak
May 9-10	78	86	82.0	do	53	43	48.0	do
June 12-13	85	83	84.0	do	7	17	12.0	do
July 16-18	78	91	84.5	Fairly vigorous	4	45	24.5	Very weak
Sept. 1-2	92	77	84.5	do	35	64	49.5	Weak
Oct. 14-15	91	86	88.5	do	..	..	...	
Dec. 8-9	85	88	86.5	Vigorous	..	..	...	
1925								
Jan. 7-8	80	83	81.5	Vigorous	..	..	...	
Feb. 4-5	92	94	93.0	do	83	77	80.0	Very weak
March 14-15	83	77	80.0	Fair	..	..	...	

* Experiment started March 10, 1924.

Not only did the spores of Form 12 remain viable in large quantities of water, but they were able to produce typical lesions on wheat and barley after they had been kept under water an entire year.

TABLE XXVII

EFFECT ON VITALITY OF SPORES OF *H. sativum*, FORMS 1 AND 12, RESULTING FROM STORAGE IN WATER CONTAINING HOST TISSUE*

	Percentage of germination											
	Tap water						Tap water with host tissue					
Date of test	Form 1			Form 12			Form 1			Form 12		
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.
1924												
Oct. 15-16	96	88	92.0	97	98	97.5	53	28	40.5	28	12	20.0
Nov. 10-11	81	83	82.0	96	91	93.5	9	17	13.0	0	0	0.0
Dec. 8-9	70	86	78.0	95	96	95.5	10	6	8.0	4	5	4.5
1925												
Jan. 7-8	79	94	86.5	90	96	93.0	18	22	20.0	7	3	5.0
Feb. 5-6	99	97	98.0	98	97	97.5	12	19	15.5	3	6	4.5
March 15-16	98	98	98.0	98	97	97.5	3	10	6.5	?	T+	T+

* Experiment started September 8, 1924.

The viability of conidia of *H. sativum* when exposed under various conditions has been studied. The data obtained are presented in Table XXVIII. The fungus was cultured on wheat heads, as previously described. The lots exposed in the greenhouse and outdoors were bound in small packets with cheesecloth covering. The sample stored in the greenhouse was attached to a cross-bar by a string. The packet put

outside was suspended beneath the eaves of the greenhouse and thus protected from the rain and direct rays of the sun. Those in the icebox and in the laboratory were put in large open test tubes. The data prove that the conidia of *H. sativum* can retain their viability for months, even years, under diverse conditions if they are kept relatively free from moisture.

XXVIII

VIABILITY OF CONIDIA OF *H. sativum*, FORM 1, EXPOSED UNDER VARIOUS CONDITIONS FROM OCTOBER, 1922, TO DECEMBER, 1924

Location of spores	Percentage of germination								
	Stored 7 mo.			Stored 17 mo.			Stored 26 mo.		
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.
Greenhouse (light)	95	95	95.0*	98	96	97.0	86	76	81.0
Under eaves outside (light)	96	92	94.0	27	39	33.0	†	..	...
Icebox (dark)	97	92	94.5	92	91	91.5	54	45	51.0
Laboratory (light)	95	99	97.0	83	97	90.0	81	59	70.0
Check, fresh culture...	..	..	...	99	99	99.0	98	99	98.5

* Percentage for a seven-month period estimated.

† Discontinued.

The writer has previously recorded the fact that spores of *H. sativum* can retain their viability for 23 months (18). Stevens (62) reported that spores were still viable at the end of 14 months. A comparison was made of the viability of conidia of four physiologic forms of *H. sativum* stored under the same and under different conditions for 3 years (Table XXIX). More than 80 per cent of the spores of Form 4 germinated after 3 years on barley heads. There are some indications that the longevity of spores varied somewhat with the physiologic form. It was noted, however, that spores of Form 3 (not indicated in Table XXIX) frequently failed to germinate when kept under conditions similar to those for Form 1. Furthermore, the writer has lost several strains because they failed to grow after stock transfers were made. A successful transfer was made from an old culture obtained from Louise Stakman, after it had been dormant nearly 5 years. It required almost a week for the new colony to become visible to the naked eye. It is apparent from Table XXX that environmental conditions are far more important than differences in physiolgoic forms in determining the longevity of conidia.

TABLE XXIX

PERCENTAGE OF GERMINATION OF CONIDIA OF 4 PHYSIOLOGIC FORMS OF *H. sativum* STORED UNDER THE SAME AND DIFFERENT CONDITIONS FOR THREE YEARS, FROM 1921 TO 1924

Form No.	Environment	Percentage of germination			Vigor
		Ser. A	Ser. B	Av.	
1	On wheat heads and kept in laboratory, at room temperature (dark)	14	17	15.5	Weak, not branched
2	do	12	25	18.5	do
3	do	14	9	11.5	do
4	do	43	40	41.5	Many of germ tubes fairly vigorous
1	On rotted wood in laboratory (dark)	71	81	76.0	Vigorous
2	On potato dextrose agar in petri dishes in laboratory (dark)	0	0	0.0	
4	On barley heads in laboratory (dark)	85	81	83.0	Fairly vigorous
1	On wheat straw in a flask (light)	0	0	0.0	

OVERWINTERING OF CONIDIA

Previous studies (18) have shown that the mycelium of *H. sativum* overwinters in the seed and on plant remains in the field. Spores produced on agar and then put outdoors did not germinate the next spring. Henry (37), however, found that a rather high percentage of conidia of *H. sativum* overwintered. It has already been mentioned (Table XXVI) that conidia of *H. sativum* put outdoors in the fall remain viable until the fall of the following year. In the present work, overwintering studies were made for 4 years. Conidia were put outdoors in the fall, and germination tests were made the following spring. The results for the last 3 years are summarized in Table XXX. The results show clearly that spores of *H. sativum* overwinter under varying conditions in the vicinity of St. Paul. The mortality of the conidia varied from one year to another, altho placed in the same locality each year. In the same year there was a great variation in the percentage of spores that remained viable after being buried at different depths in the soil.

In 1923, 2.5 per cent of the spores germinated when buried from 6 to 8 centimeters in the soil. In 1924, 81.5 per cent germinated; and in 1925, 17 per cent. Similar fluctuations were obtained also for spores stored on the surface and buried just below the ground-line.

The results of the writer's studies on the vitality and germination of spores indicate clearly that the pathogene is well fortified against adversity. The spores can withstand low as well as high temperatures if the relative humidity is favorable. Furthermore, they can withstand long periods of alternate freezing and thawing. They can even remain in water for a year or longer without germinating. When host tissue is added to a small quantity of water, however, the spores germinate promptly. This suggests the possibility that in nature the spores germinate readily only in contact with host tissues.

TABLE XXX

SUMMARY OF RESULTS ON THE OVERWINTERING OF CONIDIA OF *H. sativum*, FORM 1, KEPT UNDER VARIOUS CONDITIONS

Environment	Percentage of germination*								
	1922-23			1923-24			1923-25		
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.
Kept under eaves 12 feet from ground	80	90	85	..	..	...	92	90	91
Covered lightly with white sand next to greenhouse	20	15	17.5	99	99	99.0	30	48	39
On surface	5	T	2.5+	55	81	68.0	15	19	17
Buried 6-8 cm.	2	T	1.0+	82	81	81.5	90	88	89
Buried 12-16 cm.	75	95	85.0	87	90	88.5	0	0	0
Buried 25-30 cm.	..	..	...	91	96	93.5	0	0	0

* Percentage for 1922-23 estimated.

EFFECT OF ENVIRONMENTAL FACTORS ON THE DEVELOPMENT OF THE DISEASE

SEASONAL VARIATION

Field observations and numerous isolations for the last 5 years indicate that the Helminthosporium disease of cereals is present every year in practically every field of wheat and barley in Minnesota, but it is much more destructive in some years than in others (Tables XXXI and XXXII).

In 1919 a severe seedling blight of wheat developed in the spring-wheat region. In 1921 a severe epidemic of root-rot and basal stem-rot developed on a large number of barley varieties at University Farm, but in 1922 the infection on the same varieties was rather weak. In 1924 barley was infected only slightly, while wheat was severely damaged by root- and basal stem-rot. In 1921 and 1923 considerable seed infection occurred in wheat, but in 1924 the seeds were either clean or only slightly infected at harvest time. Data in Table XXXII show that there was the same relative variation in the amount of foliage infection of barley. Thus it is apparent that certain ecological factors influence profoundly the severity of the disease. A knowledge of these factors, obviously, is necessary for an effective control.

TIME OF INFECTION

Infection can occur under conditions which do not favor the development of the disease. Dosdall (24) found that germ tubes of *H. sativum* penetrated the tissue of both coleoptile and leaf at temperatures ranging from 12° to 34° C. However, the fungus may remain quiescent in host tissues for weeks under unfavorable temperature conditions.

TABLE XXXI

VARIATIONS IN REACTION OF WHEAT VARIETIES TO *H. sativum* GROWN ON INOCULATED SOIL FOR 4 YEARS AT UNIVERSITY FARM

Species and varieties	C.I. No.	Degree of infection*							
		Root- and basal stem-rot				Seed blight			
		1921	1922	1923	1924	1921	1922	1923	1924
Triticum vulgare									
Dicklow	3663	M—	M—	M—	M	L+	T	T	o
Glyndon	2870	M—	L—	M—	L+	L	o	T—	o
Huron	3315	M	L	L+	L	L	o	o	o
Marquis	3641	M—	L	L—	M	L—	T	T	o
Haynes Bluestem	2874	M—	T+	T	L+	L+	o	T	T—
Bobs	4991	M	M—	M	M—	M+	T	M—	o
Kota	5878	L	T+	L+	L	L	o	T—	o
Preston	3328	M—	L—	L+	L	L	o	T	o
Prelude	4323	L+	L	M+	..	L+	T—	o	..
Sonora	3036	M	T+	M	L+	H	T+	M	T—
Kitchner	4800	M	L—	L+	L+	L+	o	T—	T—
T. compactum									
Little Club	4066	M	L	L	L+	M—	No seed	T—	T
T. dicoccum									
Khapli	4013	M	L	H—	H	T	o	T+	T—
T. turgidum									
Alaska	5988	M+	T+	M—	M	M	T	o	T—
T. durum									
Acme	5284	M	L+	M	M+	H	L	L+	T
Iumillo selection		M—	L—	H—	M	M	T	M—	T—
Kahla	5529	M+	L—	L+	H	H	T	T+	L—
Monad	3320	M+	L+	M	H—	H	L+	L—	T
Pentad	3322	H—	M—	M	M+	H+	M—	M	T
Peliss	1584	M—	T+	M—	M	H—	L—	M+	T—

* T=trace. L=light. M=moderate. H=heavy.

TABLE XXXII

VARIATIONS IN REACTION OF BARLEY VARIETIES TO *H. sativum* GROWN ON HELMINTHOSPORIUM SICK SOIL FOR 4 YEARS

Species and varieties of barley	Degree of infection*							
	Root- and basal stem-rot				Spot blotch			
	1921	1922	1923	1924	1921	1922	1923	1924
Hordeum vulgare								
Arequipa (selection)	H+	L—	M+	L—	H+	T+	M+	L—
Bay Brewing do	H+	L—	M	L—	H+	T—	M+	L—
Manchuria Minn. 184	L+	T+	L+	T+	L+	T	L	T
Minsturdi Minn. 439	M—	L—	L	T+	H	T+	L+	L—
Mariout (selection)	M	H	M	L—	H	M—	H+	L+
Nepal do	M+	L+	M	L—	H	L	M—	T+
N. S. Wales do	M	..	H—	L	H—	..	H	L+
Trebi do	L+	L	M+	L—	M—	T+	M	T+
Lion do	M	M+	H—	L	H+	L+	M+	L—
H. distichon								
Chevalier Minn. 230	M	L—	L	T+	H—	T+	L—	T+
Hanna (selection)	M+	T+	M—	T+	H+	T+	L+	T+
Hannchen do	M+	T+	M	T+	H+	T	L+	T+
Svanhals do	M	L—	L—	T	M+	T+	L	T
Svansota Minn. 440	M—	T+	L	T	M	T	L+	T

* T=trace. L=light. M=moderate. H=heavy.

Unfavorable external and internal conditions may prevent the pathogene from becoming destructive. At St. Paul, primary lesions of *H. sativum* have been observed on the underground parts of wheat and barley sown at intervals from early April to the middle of October. Under favorable conditions secondary infections may occur repeatedly during the life of the host. Thus, the appearance and the severity of the disease depend on an environmental complex. The temperature must be favorable and a certain amount of moisture is necessary; the spores must germinate, or resting mycelium must resume its growth. Under certain conditions the fungus may grow so slowly and the host so rapidly that it may grow away from the pathogene. This, in part, accounts for some of the variations in infection observed from season to season.

INFLUENCE OF SOIL MOISTURE

The influence of soil moisture on the development of the disease on cereals at various stages of growth is imperfectly known. Dosdall (24) concluded that root-rot and basal foot-rot were more severe in extremely dry or wet soil than in soil containing an optimum amount of moisture for the growth of the plant. McKinney (47) concluded that at soil temperatures of 24° C. or higher, the disease developed better in moist soil, and that at temperatures below 24° C., low soil moisture content favored the disease.

In order to obtain additional information on the influence of soil moisture, 2 varieties of wheat and 4 varieties of barley were sown on peat with five different drainage levels. The wheat varieties used were Monad (C. I. 3320) and Pentad (C. I. 3322); the barley, Minsturdi (Minn. No. 439), Svansota (Minn. No. 440), Manchuria (Minn. No. 184), and Lion selection. The water levels were approximately 1, 2, 3, 4, and 4.5 feet below the surface. Duplicate rows 33 feet long of each of the varieties were sown on each water level in 1923 and 1924. There was a space of 33 feet between each drainage level. Notes were taken on the degree of *Helminthosporium* infection and yield. Soil temperature readings and soil moisture determinations were made at irregular intervals.

A severe epidemic of the disease developed in both years. In 1923 there was considerable seedling blight in all plots. Root-rot and basal stem-rot were most serious for all varieties on the 4- and 4.5-foot water levels. Practically all the Monad and Pentad wheat plants were killed on the 4.5-foot level, and from 50 to 70 per cent of the barley plants.

In 1924 the epidemic developed much later in the season. Monad and Pentad wheats were severely damaged on all drainage levels except the 1-foot level. The data on the number of plants killed by root- rot and basal stem-rot at two different dates are presented in Table XXXIII.

The plants in Series A which were inoculated with *H. sativum* succumbed first to the attack of the organism. In platings from diseased basal stems of uninoculated plants, 87 per cent of the colonies were *H. sativum,* indicating that this organism was the principal pathogene. Practically all the plants on the 2- to 4.5-foot drainage levels were killed after heading. Those surviving were small, diseased, and weak. At least four-fifths of the plants on the 1-foot water level developed normally and produced plump grains, altho sown late in the spring.

TABLE XXXIII

COMPARATIVE NUMBERS OF WHEAT PLANTS KILLED IN 1924 BY ROOT- AND BASAL STEM-ROT ORGANISMS WHEN GROWN ON PEAT SOIL WITH FIVE DIFFERENT DRAINAGE LEVELS

Drainage levels, feet	Variety	Percentage of culms dead*				Remarks
		Series A†		Series B		
		Aug. 28	Sept. 9	Aug. 28	Sept. 9-24	
1	Monad	14	15	13	17	Heads large, plants upright
1	Pentad	12	12	10	20	do
2	Monad	20	96	12	85	Weak plants lodged
2	Pentad	23	95	11	69	do
3	Monad	29	98	18	89	do
3	Pentad	23	99	14	74	do
4	Monad	22	93	10	86	do
4	Pentad	31	98	9	86	do
4.5	Monad	14	97	11	59	Most of living plants late, small
4.5	Pentad	15	95	11	58	do

* Percentage on August 28 based on a count of 400 culms; on September 9, on 200 culms for each series.

† Series A, soil inoculated with *H. sativum;* series B, control.

The relative amount of water in the six different drainage levels at from 1 to 2 inches below the surface was approximately the same for all plots except the 1-foot level (Table XXXIV) which contained an average of 100 per cent more moisture than the others. The percentage of Monad and Pentad wheat plants killed is correlated negatively with the amount of moisture present in the soil. It is interesting to note that two varieties of durum wheat could grow apparently normally in peat soil saturated with moisture.

TABLE XXXIV

RELATIVE AMOUNTS OF WATER IN PEAT SOIL WITH FIVE DIFFERENT DRAINAGE LEVELS, 1924

Drainage level, feet	Percentage of moisture at a depth of from 1 to 2 in.				
	July 8	July 17	Aug. 28	Sept. 9	Average
1	303	300	327	405	333.7
2	199	196	238	126	189.7
3	184	181	217	123	176.2
4	195	183	208	233	204.7
4.5	191	184	206	176	189.2

Temperature readings of peat soil with five different drainage levels were taken at different times and on different dates, as shown in Table XXXV. Readings were made at identical places in the six different series. Three separate readings were made on every plot for each test. The results show a uniformity of temperature on all levels at the time the readings were made. The data also show that the temperature of peat soil may fluctuate several degrees during a few hours.

TABLE XXXV

AVERAGE COMPARATIVE TEMPERATURES* OF PEAT SOIL ON FIVE DIFFERENT DRAINAGE LEVELS IN 1924

Date of readings	Depths of readings, cm.	Temperature (° C.) at different water levels				
		1 foot	2 feet	3 feet	4 feet	4.5 feet
June 25	6-7	23.8	24.5	24.3	24.3	24.8
June 25	2-3	30.8	30.6	30.0	29.5	31.6
Sept. 2	6-7	20.3	20.1	20.1	20.5	20.3
Sept. 2	2-3	23.8	23.1	23.6	22.8	23.8
Sept. 9						
10-11 a.m.	6-7	13.1	13.0	13.1	13.1	13.1
3-4 p.m	6-7	18.8	19.0	18.8	19.1	20.0
Mean average	..	21.7	21.7	21.6	21.5	22.2

* Average of three readings in different locations.

The rate of growth of fungi on culture media was used to determine the possible constancy in temperature at different water levels over a period of 13 days. Large test tubes, 25 cm. by 2.5 cm., containing 20 cc. of potato dextrose, were slanted so as to give a lateral surface for growth of at least 15 cm.. Twelve of these tubes were inoculated in the center of each slant. Two of the tubes were buried on each water level in different places from 6 to 8 cm. beneath the surface of the soil. After 13 days they were dug up and the radial spread of the colonies was measured. Table XXXVI contains the data. The greatest difference in radial spread was 0.05 cm. in tubes which were buried in the 3- and 4-foot water levels. The differences in development of cultures at high and low drainage level is only 0.01 cm. This surely is not significant.

TABLE XXXVI

COMPARATIVE RATE OF SURFACE GROWTH OF *H. sativum* ON POTATO DEXTROSE AGAR WHEN BURIED 6-8 CM. IN PEAT SOIL WITH FIVE DIFFERENT DRAINAGE LEVELS

Depth of drainage, feet	Diameter of colonies, cm.*			Av. growth of colonies per day, cm.
	Ser. A	Ser. B	Av.	
1	3.5	3.3	3.40	0.26
2	3.2	3.2	3.20	0.24
3	3.2	3.3	3.25	0.25
4	4.2	3.8	4.00	0.30
4.5	3.6	3.5	3.55	0.27

* Period of 13 days—June 25 to July 8, 1924.

The data in Tables XXXV and XXXVI seem to prove that the slight variation in temperature at the six different water levels can not account for the differences in the killing of the two varieties of wheat grown there. The variation in the percentage of killing, therefore, would probably have to be explained primarily on the basis of soil temperature. The basal stems of diseased plants were usually discolored. The roots adjoining them were often badly diseased or rotted. It is possible that the water supply of the diseased plants was materially reduced. The roots and stems of the plants on the 1-foot water level usually were not so distinctly discolored as those in the other plots. It seems safe to conclude that high soil moisture either inhibits the growth of *H. sativum* or renders the plants less susceptible. Perhaps the proximity of the moisture enables the plants on the 1-foot water level to obtain sufficient moisture during the critical period, which insures normal filling of the kernels. In 1924 the wheat varieties were a total failure on all except the 1-foot level. In general the varieties of barley did equally well on the 2-, 3-, and 4-foot drainage levels in 1923. In 1924 the barley varieties yielded fairly well, also, on the 4.5-foot level. These results indicate that wheat and barley respond differently to soil moisture. Wheat with basal stem-rot developed best on plots with relatively shallow surface drainage, and barley on the plots with intermediate surface drainage.

In 1923 and 1924 Minsturdi barley produced the highest mean yield in all plots. The yields undoubtedly would have been even higher except for the fact that in both years from 5 to 10 per cent of the plants were infected with *H. gramineum*. No attempts were made to control the disease. Manchuria, Minn. No. 184, was very susceptible to freckles, a physiologic disease which caused considerable damage at times to varieties of barley grown on peat, especially Manchuria. The results indicate that the lowering of soil moisture to a point where metabolism of the wheat or barley plant becomes abnormal, predisposes them to attack by *Helminthosporium*. This statement is supported by laboratory tests and field observations. *Helminthosporium* disease is destructive on peat soil because the organism will grow and fructify on the organic matter in peat, and because insufficient or unbalanced nutrition predisposes the host plants. Heavy dews favor foliage and spike infection. A paucity of available soil moisture inhibits the growth of the diseased plants. It is apparent from these experiments and observations that foliage infection, root- and basal stem- rot caused by *Helminthosporium* and other organisms are limiting factors in cereal production on peat soil.

EFFECT OF TIME OF PLANTING ON DEVELOPMENT OF *H. SATIVUM*

In order to obtain data on the influence of temperature on the *Helminthosporium* disease and on the relation of the degree of susceptibility of the host plants in various stages of development, several sowings of wheat and barley were made at various intervals. Each sowing consisted of 3 seven-foot rows of each variety. In 1924 Marquis, C. I. 3641, and Monad, C. I. 3320, wheats; and Manchuria Minn. No. 184, and Lion selection barleys were used. In 1923 only the barley varieties were sown. In 1924 notes were taken at intervals as indicated in Tables XXXVII and XL. The soil was inoculated on the date of sowing by applying inoculum grown on sterilized wheat kernels.

Table XXXVII indicates that environment influences the development of seedling blight and basal stem-rot to a much greater extent than does the stage of host development. Thus, early-sown Lion and Manchurchia barleys were infected only slightly, but the same varieties sown on June 4 became heavily infected with root-rot. Fifty per cent of the Manchuria plants sown on July 9 were killed before they reached the boot stage. For several weeks the early-sown wheat plants remained relatively free from root-rot. However, as the season advanced and these plants began to mature, they developed a severe root- and basal stem-rot. Field observations indicate that the barley and wheat varieties pass through a stage in which they are somewhat resistant to root- and basal-stem rot. This period of apparent resistance extends from the time of development of adventitious or permanent roots, to the heading stage. From the milk stage to maturity, root-rot, and (especially) basal stem-rot, developed very rapidly.

The degree of infection depends to a marked extent upon the host and the environmental conditions. Henry (37) is of the opinion that adventitious roots are more resistant than seminal roots to many root-rot pathogenes. This resistance is not absolute, because the killing of plants in all stages of development by *H. sativum* is not uncommon.

In the winter of 1923 more than a thousand pots of wheat from 2 to 4 weeks old were inoculated with cultures of *H. sativum* in the greenhouse. In every case the roots and basal portion of the stem became diseased. Some of the plants were stunted and many died throughout the course of the experiment.

Results given in Table XXXVIII show that the greatest percentage of plants killed after heading occurred in the plots sown early in the season. Only a few of the plants sown after the middle of June succumbed. The mortality of the plants was greatest during the latter part of July and the first two weeks in August. The plants continued to die prematurely up to the hard dough stage. In every case Monad was injured to a much greater extent than Marquis.

TABLE XXXVII

DEGREE OF FOLIAGE INFECTION ON BARLEY AND ROOT- AND BASAL STEM-ROT INFECTION FOR MARQUIS AND MONAD WHEAT AND MANCHURIA AND LION BARLEY GROWN ON ARTIFICIALLY INOCULATED SOIL

Host	Date sown	Degree of infection and stage of host*													Remarks
		June 6			July 1			July 21			Aug. 25			Sept 2	
		Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Root-rot	
Manchuria	Apr. 30	T—	T—	14	T	T	H	T	T	HD					
Lion	do	T	T—	12	T+	T	H	L	T+	HD					
Marquis	do		T	12		L—	B		L—	SD		L+	R		
Monad	do		T	10		L	J		L	SD		H	R		
Manchuria	May 12	T—	L—	8	T—	T—	Hg	T	T	SD					
Lion	do	T—	L—	8	T	T+	Hg	L	T+	SD					
Marquis	do		T+	6		T+	J		T+	M		M—	R		
Monad	do		M—	6		L—	16		L—	M		H	R		
Manchuria	May 15	T—	T	10	T	T	B	T	T	SD					
Lion	do	T—	T	8	T+	L—	Hg	L—	T+	SD					
Marquis	do		T	8		T+	J		L—	M		M	R		
Monad	do		L—	7		L—	J		L—	M		H	R		
Manchuria	May 21	T—	T	7	T—	T—	J	T—	L—	SD					
Lion	do	T	T—	5	T+	T+	B	T—	L	SD					
Marquis	do		L+	6		L	J		L	Fl		M+	R		
Monad	do		L+	6		L	J		L+	Fl		H	R		
Manchuria	May 28	0	T—	5	T—	T—	J	T	L—	M					
Lion	do	0	T	4	T+	T+	J	T+	L	M					
Marquis	do		T	4		L+	12		L	Fl		M	R		
Monad	do		T	4		L	12		L+	Hg		H	HD		

TABLE XXXVII—*Continued*

Host	Date sown	Degree of infection and stage of host*												Remarks	
		June 6			July 1			July 21			Aug. 25			Sept 2	
		Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Root-rot	
Manchuria	June 4	o	T—	3	T—	T—	10	T—	L	Fl		H—			
Lion	do	o	T—	2	T—	T+	7	T	M—	Hg		H—			
Marquis	do		T—	3		L+	6		M—	B		H	HD		
Monad	do		T—	3		L+	7		M	B		H	HD		
Manchuria	June 12				T—	T—	5	T—	L+	B	L	H	HD		
Lion	do				T—	T—	5	T	L+	B	M—	H	HD		
Marquis	do					T+	4		M—	J		M—	SD		
Monad	do					T—	4		M	J		M	M		
Manchuria	June 18				o	L—	3	T	L	J	L+	H—	HD		
Lion	do				T	T	3	T	L+	J	M	H	HD		
Marquis	do					L	3		M—	8		H—	M	H—	Poor stand
Monad	do					L+	3		M+	6		H	Fl	H—	Poor stand
Manchuria	June 25				o	o	1	T—	M—	6	L—	H	M	H—	
Lion	do				o	o	1	T—	M—	4	M	H	SD	H—	
Marquis	do					o	1		M+	4		H	T	H	75% of plants killed mostly in seedling and jointing stage
Monad	do					o	1		M+	4		H	Hg	H	75% of plants killed mostly in seedling and jointing stage
Manchuria	July 2							T—	M—	6	T+	M—	Hg	H	
Lion	do							T—	M—	4	M	M	Fl	H	25% killed
Marquis	do								M+	4		H+	B	H	
Monad	do								M+	3		H+	J	H	75% killed
Manchuria	July 9							o	T+	3	T	L+	J	L	50% killed
Lion	do							o	L+	3	T+	L+	B	L+	20% killed
Marquis	do								T+	2		H	J	L+	50% killed
Monad	do								T+	2		H	8	L	10% killed

TABLE XXXVII—*Concluded*

Host	Date sown	Degree of infection and stage of host*												Remarks	
		June 6			July 1			July 21			Aug. 25			Sept 2	
		Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Leaf spot	Root-rot	Stage, in.	Root-rot	
Manchuria	July 21										T	L+	8	L	Good stand
Lion	do										L+	L+	8	L	do
Marquis	do											H	6	L	20% killed†
Monad	do											H	6	L	10% killed†
Manchuria	July 28										T	L—	6	T+	
Lion	do										T	L—	6	T+	Very good stand
Marquis	do											M—	4	T+	
Monad	do									...		M—	4	T+	
Manchuria	Aug. 6										T—	L—	6	T—	
Lion	do										T—	L—	6	T	Vigorous growth and
Marquis	do											T	6	T—	excellent stand
Monad	do											T	6	T—	
Manchuria	Aug. 15										o	T—	4	T—	
Lion	do										o	T—	4	T—	do
Marquis	do											T+	4	T—	
Monad	do											T+	4	T—	

* Symbols expressing stages of development:

B=Boot Hg=Heading Fl=Flower SD=Soft dough R=Ripe

J=Jointing H=Headed M=Milk HD=Hard dough

† Plants recovering.

A study of Table XXXVII shows that very little foliage infection occurred during the summer of 1924. The low foliage infection is correlated with a low percentage of seed infection of wheat (Tables XXXI, XXXII, and XLIX). In 1921, when barley leaves were heavily infected, there was also a severe seed blighting of wheat. Heavy foliage infection in 1921 seemed to be correlated with a combined high mean temperature and high precipitation for the month of July (Table XXXIX). The small grains were harvested during this month. In 1923 a moderate foliage infection developed on barley varieties. In that year July was hot, but the amount of precipitation was not high. The mean temperature during July in 1922 and 1924 was low. In these two years the foliage infection also was low. The data given in Table XXXIX seem to indicate that a high temperature combined with a moderate to high rainfall favors abundant foliage and seed infection.

TABLE XXXVIII

RESULTS OF PLANTING WHEAT ON DIFFERENT DATES IN RELATION TO THE NUMBER OF CULMS KILLED BY ROOT- AND BASAL STEM-ROT ON SOIL ARTIFICIALLY INOCULATED WITH *Helminthosporium*, 1924

Date of planting	Variety	Percentage of culms dead on different dates*			Stage of development on different dates		
		Aug. 13	Sept. 2	Sept. 11	Aug. 13	Sept. 2	Sept. 11
April 30	Marquis	14			Ripe		
do	Monad	92			do		
May 12	Marquis	15			do		
do	Monad	84			do		
May 15	Marquis	14			do		
do	Monad	90			do		
May 21	Marquis	8			Hard dough		
do	Monad	26			do		
May 28	Marquis	11			Soft dough		
do	Monad	21	53		do	Ripe	
June 4	Marquis	2	8		do	do	
do	Monad	8	35		Milk	Hard dough	
June 12	Marquis	1	3	3	do	do	Ripe
do	Monad	3	12	20	Flower	Soft dough	Hard dough
June 18	Marquis	0	3	3	do	do	do
do	Monad	0	4	6	Headed	Milk	Soft dough
June 25	Marquis		0	T—	Heading	do	do
do	Monad		0	T	Boot	Flower	Milk
July 2	Marquis		0	0		do	do
do	Monad			0		Boot	Heading

* Plants that have headed out, seedling blight not considered.

TABLE XXXIX

PREVAILING WEATHER CONDITIONS AT ST. PAUL FOR FOUR MONTHS, 1919-24*

Year	Mean temperature				Total precipitation			
	May	June	July	August	May	June	July	August
	Deg.	Deg.	Deg.	Deg.	In.	In.	In.	In.
1919	57.5	69.1	72.7	68.2	2.17	4.75	6.15	1.41
1920	59.0	68.0	70.2	69.2	2.34	9.64	1.35	0.96
1921	59.8	73.5	76.7	70.0	4.10	3.19	4.27	1.05
1922	62.5	68.3	68.8	72.0	2.86	6.76	1.73	1.55
1923	58.6	70.0	75.2	66.9	3.05	4.95	2.90	1.90
1924	49.8	63.6	69.0	67.0	1.47	7.24	1.73	6.51
Average	57.8	68.7	72.1	68.8	2.66	6.08	3.02	2.23

* Data obtained from U. S. Dept. Agr. Weather Bureau.

Tables XXXVII and XL both indicate that variation in foliage infection was not correlated to any great extent with stages of development. In general, a higher degree of infection occurs on more advanced plants, e.g., those in the soft or hard dough stage, than on young seedlings. This probably is because older plants were exposed to inoculation for a longer time than the seedlings. There is some evidence that leaves on small barley seedlings are less susceptible than those on older plants (18 and 60). Seedling blight is not nearly so detrimental to grain culture as the basal stem-rot which occurs later in the season. Unless the blight results in the killing of plants in definite patches, the plants that survive the seedling blight will often tiller to a much greater extent than normally and thus counteract the loss in stand resulting from seedling blight. It is, however, of great importance to remember that when seedling blight is severe, necrosis of the secondary culms frequently results before they emerge from the ground. Further, this in turn is often followed by considerable rot of permanent roots and of the bases of culms. The fact that many seedlings are also stunted early in the season and often apparently recover must not be overlooked. These plants can by no means yield as much or produce as good grain as plants which have grown normally.

TABLE XL

DEGREE OF FOLIAGE, ROOT, AND BASAL STEM INFECTION ON BARLEY ARTIFICIALLY INOCULATED, 1923

Variety	Date planted	Stage of development*	Degree of root and basal stem infection	Degree of leaf infection
Manchuria	Apr. 27	Ripe	M	L
Lion	" 27	do	H—	H
Manchuria	May 1	do	M—	L+
Lion	" 1	do	H—	H—
Manchuria	" 5	Practically ripe	L+	L—
Lion	" 5	do	M+	M+
Manchuria	" 9	do	L	L
Lion	" 9	do	M	H
Manchuria	" 12	Hard dough	L+	L—
Lion	" 12	do	M	H—
Manchuria	" 16	Headed	L	L—
Lion	" 16	do	M—	H—
Manchuria	" 25	Heading	L	L
Lion	" 25	Just headed	L+	M
Manchuria	June 1	Boot stage	L	M
Lion	" 1	do	L+	M+
Manchuria	" 9	Seedlings	L—	M—
Lion	" 9	Boot stage	L+	M+
Manchuria	" 16	Seedlings	T+	M—
Lion	" 16	do	L—	M+

* Notes were taken July 19, 1923.

EFFECT OF TIME OF PLANTING ON DEVELOPMENT OF *H. GRAMINEUM*

Reference to Table XLI and Figure 2 will show that early sowing in the spring increases the amount of barley stripe infection. The data also show that no infection occurs during the hottest part of the summer, but the disease develops again in the latter part of the summer and early fall. Thus the two diseases caused by *H. sativum* and *H. gramineum* are influenced differently by temperature. Johnson (39) has recently found that low soil temperatures (10° to 12° C.) favor infection of barley by *H. graminum* Rab. under controlled experimental conditions. Very little stripe occurred at soil temperatures higher than 20° C. McKinney (47), Henry (37), and others have concluded that high temperatures are conducive to seedling infection caused by *H. sativum*. Dosdall (24) demonstrated that rather high temperatures were most favorable for the growth of the organism, for spore germination, and for the development of the disease.

TABLE XLI

EFFECT OF DATE OF SOWING ON DEVELOPMENT OF BARLEY STRIPE IN 1923 AND 1924

Date of sowing		Percentage of stripe*	
1923	1924	1923	1924
Apr. 27	Apr. 30	14.0	20.2
May 1	May 12	13.5	15.8
" 4	" 15	17.0	17.2
" 9	" 21	7.5	12.8
" 12	" 28	9.5	4.2
" 17	June 4	2.0	4.0
" 21	" 12	0.	0.6
" 25	" 18	0.	0.
" 31	" 25	0.	0.
....	July 2	...	0.
....	" 9	...	0.
....	" 21	...	0.
....	" 28	...	0.6
....	Aug. 6	...	1.2
....	" 14	...	4.2

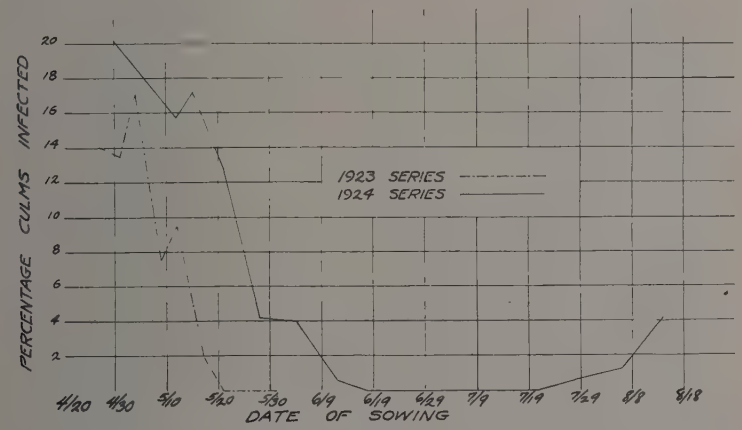


Fig. 2. Effect of Date of Sowing on Development of Barley Stripe in 1923 and 1924

PREDISPOSITION OF THE HOST

The influence of moisture and temperature on the development of the pathogene and the disease has been discussed in some detail. It may be that the influence of these factors, especially temperature, is more important on the host than on the organism. High temperatures are favorable to the fungus but unfavorable to wheat and barley. Dickson's work (22) and that of Eckerson and Dickson (27) and others tend to indicate that the temperatures which predispose the host are more important than those which influence the development of the pathogene. It has been shown that *Gibberella saubinetii* blights corn most severely at low temperatures and wheat at relatively high temperatures.

Predisposition plays an extremely important part in the degree of infection of *H. sativum*. Even the most resistant varieties known may be severely attacked under conditions unfavorable for the host but favorable for the pathogene. Thus, during the summer of 1923, Manchuria, Minn. No. 184, a resistant variety of barley (33), was so severely attacked by *H. sativum* on peat soil that many plants were killed in the seedling stage and plants continued to die throughout the season. Two other varieties of barley and 3 of wheat were similarly attacked (Table XLII).

TABLE XLII

EFFECT OF SOIL TYPE ON DEVELOPMENT OF FOOT-ROT AND ROOT-ROT OF WHEAT AND BARLEY IN 1923 AND 1924

Cereal and variety	Degree of infection			
	Hempstead loam, University Farm		Peat soil,* Purgo swamp	
	1923	1924	1923	1924
Wheat				
Monad, C. I. 3320	M	H—	H+	H+
Marquis, C. I. 3641	L—	M	H	H—
Pentad, C. I. 3322	M	M+	H+	H+
Barley				
Manchuria, Minn. No. 184	L	T	H+	M—
Lion selection	H	L—	H+	M—
Svansota, Minn. No. 440	L	T	M+	L+

* On 4.5-foot drainage level.

The injury was chiefly due to leaf infection and to basal stem-rot. The roots, in general, were not severely attacked. In these tests Manchuria exhibited no real resistance, which emphasizes the fact that resistance to *H. sativum* is only relative and not absolute.

Since the organism is usually present in the soil or on the seed, and as spores are blown long distances by the wind, nearly all wheat and barley plants eventually become infected with the organism. When a resistant host is weakened by unfavorable conditions, it usually becomes severely infected. The reaction of the soil determines to a great degree the extent of infection. The disease was always worse in alkali spots than on land immediately adjoining them. This was undoubtedly due to the fact that the host had become weakened rather than to the effect of soil reaction on the pathogene.

There are great variations in the severity of *Helminthosporium* root-rot and basal stem-rot in adjoining fields. Some fields are practically free from the disease, while others are severely infected. There are all gradations between these extremes. Altho the variety of grain grown may be the same and the topography of the fields identical, the disease is nearly always most destructive in poorly tilled fields.

Field observations and experiments indicate that the disease is most destructive on the underground parts of the plants in peat soils and sandy soil. Data in Table XLIX show that the disease caused more damage to roots of plants on sandy soil than to those on heavier soils. This was the case in 1923. But in 1924, there was as much root infection in one type of soil as in the other. An early drying-out of the sandy soil in 1924 brought about a premature death of the plants as well as a cessation of the activity of the fungus.

The apparently great susceptibility of wheat and barley to basal stem-rot on sandy soil may be explained partly by the effect of temperatures on the host, rather than on the fungus. Soil temperature readings were made on sandy soil at Coon Creek, July 12, 1924, between the rows of cereals, one foot apart and at a depth of one inch. The temperature was high throughout, ranging from 44° to 48°, and altogether too high for the normal functioning of the plants.

From the above data and discussion, it is evident that the extent to which wheat and barley plants are affected by *Helminthosporium* depends on such environmental factors as air temperature, soil moisture, aeration, and precipitation. The host reaction depends also upon the type of soil, the amount of plant food available, the tilth of the soil, and the soil temperature. The degree of infection was influenced profoundly by the amount of inoculum, the physiologic form of *H. sativum* concerned, and the genetic constitution of the host plants involved.

EFFECT OF SEED TREATMENT ON THE PATHOGÉNE AND THE HOST

EFFECT OF SEED TREATMENT ON GERMINATION

There are rather conflicting reports on the effect of various fungicides upon seed germination (3, 45, 55, and 66). In order to obtain additional information, the following experiment was carried out: 3 varieties of wheat, Marquis, Monad, and Pentad; and 4 varieties of barley, Arequipa, Lion, Manchuria, and Svansota, were treated with six chemical dusts and ten liquid fungicides. Germination tests were made in the greenhouse on flats 3 x 4 feet, containing a mixture of sand and soil infected with pathogenic fungi obtained from an experimental plot. Each treatment was tried in duplicate rows, 100 seeds being sown to each row. These comparative germination tests are summarized in Tables XLIII and XLIV.

A study of the data will reveal in many cases appreciable increase in germination, especially for wheat treated with the liquid mercuric compounds. The writer realizes that these treatments should have been repeated several times and statistical methods applied in order to be conclusive. The differences between the control and the treatment in many cases were consistent and warrant some discussion. Chlorophol, Semesan, Uspulun, silver nitrate, and Tillantin greatly increased the percentage of germination of wheat. Flower of sulphur and white Seed-O-San decreased the percentage of germination for all three varieties of wheat. Copper carbonate did not affect the germination of durum wheat, but it probably increased that of Marquis.

TABLE XLIII

EFFECT OF TREATMENT WITH VARIOUS CHEMICALS ON THE PERCENTAGE OF GERMINATION OF WHEAT SEED

Treatment	Percentage of germination*									
	Marquis			Monad			Pentad			
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Av. of 3 varieties
Dusts										
Check—none	72	68	70.0	66	75	70.5	62	66	64.0	68.2
Nickel carbonate 4 oz. per bu.	85	79	82.0	58	56	57.0	59	77	68.0	69.0
Copper carbonate 4 oz. per bu.	90	90	90.0	83	81	82.0	81	78	79.5	83.8
Copper sulphate and lime, 4 oz. per bu.	80	85	82.5	75	66	70.5	74	68	71.0	74.6
Seed-O-San (pink) 3 oz. per bu.	95	95	95.0	84	74	79.0	83	77	80.0	84.7
Seed-O-San (white) 4 oz. per bu.	65	60	62.5	62	73	67.5	63	78	70.5	66.8
Flower of sulphur 4 oz. per bu.	84	81	82.5	47	42	44.5	41	43	42.0	56.3
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	99	91	95.0	92	88	90.0	94	93	93.5	92.8
Tillantin "C" 0.25% soaked 2 hrs. cold	93	95	94.0	80	75	77.5	95	97	96.0	89.2
Semesan 0.3% soaked 2 hrs. ...	89	96	92.5	92	92	92.0	96	98	97.0	93.8
Silver nitrate n/100 soaked 2 hrs.† ...	91	95	93.0	90	90	90.0	88	96	92.0	91.7
Germisan 0.25% soaked ½ hr. cold ..	85	85.0	78	76	77.0	85	76	80.5	80.8	
Germisan 0.25% soaked 1½ hrs. cold	82	81	81.5	89	84	86.5	84	89	86.5	84.8
Uspulun 0.25% soaked 1 hr. cold	88	89	88.5	88	89	88.5	91	84	87.5	88.2
Uspulun 0.25% soaked 2 hrs. cold	90	87	88.5	93	85	89.0	93	98	95.5	91.0
Uspulun 0.25% soaked ½ hr. 40-45° C.	92	93	92.5	88	93	90.5	94	92	93.0	92.0
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	94	91	92.5	94	100	97.0	95	92	93.5	94.3

* Count in each series based on 100 seeds.

† Treated in all cases as cited in reference (24).

TABLE XLIV

EFFECT OF TREATMENT WITH VARIOUS CHEMICALS ON PERCENTAGE OF GERMINATION OF BARLEY SEED

Treatment	Percentage of germination*												
	Manchuria			Lion			Arequipa			Svansota			Av. of 4 varieties
	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	
Dusts													
Check—none	90	92	91.0	98	87	92.5	87	90	88.5	87	87	87.0	89.7
Nickel carbonate, 4 oz. per bu.	90	89	89.5	100	82	91.0	84	99	91.5	92	94	93.0	91.2
Copper carbonate, 4 oz. per bu.	88	..	88.0	91	80	85.5	80	90	85.0	89	87	88.0	86.6
Copper sulphate and lime, 4 oz. per bu.	91	92	91.5	94	92	93.0	84	78	81.0	83	91	87.0	88.1
Seed-O-San (pink), 3 oz. per bu.	90	99	94.5	93	89	91.0	90	90	90.0	94	94	94.0	92.4
Seed-O-San (white), 4 oz. per bu.	97	97	97.0	90	90	90.0	87	79	83.0	100	93	96.5	91.6
Flower of sulphur, 4 oz. per bu.	85	92	88.5	95	85	90.0	80	82	81.0	88	93	90.5	87.5
Liquids													
Chlorophol 0.25% soaked 2 hrs.	92	100	96.0	99	91	95.0	97	92	94.5	99	98	98.5	96.0
Tillantin "C" 0.25% soaked 2 hrs.	94	97	95.5	94	92	93.0	92	97	94.5	91	96	93.5	94.1
Semesan 0.3% cold soaked 2 hrs.	87	97	92.0	95	96	95.5	94	94	94.0	97	95	96.0	94.4
Silver nitrate cold n/100 soaked 2 hrs.	98	94	96.0	91	90	90.5	92	99	95.5	100	99	99.5	95.4
Germisan 0.25% cold soaked ½ hr.	94	92	93.0	94	95	94.5	92	89	90.5	90	89	89.5	91.9
Germisan 0.25% cold soaked 1½ hrs.	93	94	93.5	92	90	91.0	87	100	93.5	94	93	93.5	92.9
Uspulun 0.25% cold soaked 1 hr.	93	96	94.5	100	91	95.5	95	96	95.5	99	98	98.5	96.0
Uspulun 0.25% cold soaked 2 hrs.	100	95	97.5	93	95	94.0	100	100	100.0	98	99	98.5	97.5
Uspulun 0.25% soaked ½ hr. 40-45° C.	97	98	97.5	100	92	96.0	94	97	95.5	95	94	94.5	95.9
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	96	97	96.5	91	96	93.5	97	94	95.5	96	96	96.0	95.4

* One hundred seeds planted in each series.

The results of treating barley seed, presented in Table XLIV, are not so striking as those given in Table XLIII for wheat. In general, the relative percentage of germination of barley for the various treatments was similar to that noted for wheat. Apparently certain chemicals stimulate while others repress the percentage of germination of cereal seeds. The percentage of germination of untreated barley was much higher than that of untreated wheat, consequently there was less chance for stimulation in the barley than in the wheat; but the various fungicides seemed to affect both cereals similarly.

Increased percentage of germination has been attributed to the stimulatory effect of fungicides on seed and their effectiveness in controlling soil fungi. Many of the reports are conflicting. For this reason seeds of Mariout barley severely infected with *H. sativum* were treated with several fungicides. The treatments used are those listed in Table XLV. For each treatment 40 seeds were used. Twenty of these were plated out on two petri dishes of potato dextrose agar. The same number were sown in petri dishes containing moist sterilized white sand. For dust treatments, the seeds were rolled in an excess of the chemicals. Often considerable amounts adhered to the seeds after they were transferred to the plates.

TABLE XLV

Effect of Various Chemical Dusts and Liquid Fungicides on Fungi in or on the Seed of Mariout Barley

Treatment	Percentage of colonies developed on potato dextrose agar		Percentage of seeds and seedlings on which *Helminthosporium* developed in sand	
	Helminthosporium sativum	Other fungi	Seed	Shoots
Dusts				
Check—none	85	15	55	100
Nickel carbonate, 4 oz. per bu.	90	10	65	100
Copper sulphate and lime, 4 oz. per bu.	90	10	75	100
Copper carbonate, 4 oz. per bu.	95	5	90	100
Seed-O-San (pink), 3 oz. per bu.	65	10	45	90
Seed-O-San (white), 4 oz. per bu.	95	5	70	100
Sulphur dust, 4 oz. per bu.	95	5	80	100
Liquids				
Chlorophol 0.25% soaked 2 hrs. cold	01	5	0	100
Tillantin "C" 0.25% soaked 2 hrs. cold	10	45	30	80
Semesan 0.3% cold soaked 2 hrs.	80	10	35	100
Silver nitrate cold n/100 soaked 2 hrs.	70	10	0	80
Germisan 0.25% cold soaked ½ hr.	55	35	..	..
Germisan 0.25% cold soaked 1½ hrs.	60	25	..	..

The data in Table XLV show that none of the dust compounds killed the fungi on or in the seed. *H. sativum* and other fungi sporulated profusely on seed thus treated (Plate XII). Some liquid fungicides partially controlled *Helminthosporium*. Of these, Chlorophol and Tillantin were the most effective, but even these compounds merely

retarded the development of the pathogene. Eventually, in the sand cultures, discoloration became conspicuous and sporulation abundant on the basal portion of the young seedlings. These results indicate that the increase in percentage of germination with the dusts used can not always be explained on the basis of killing of the fungi within the seed. On the other hand, the results with a few of the liquid treatments seem to indicate that the chemicals retard the development of the pathogene in the seed and consequently lessen its injurious effect on seed germination.

The conflicting opinions regarding the effectiveness of seed disinfection can be explained to a certain extent. Various workers have used different varieties of cereals which were infected to different degrees. In 1923 Atanasoff (3) concluded that fungicides can not free internally-infested kernels from *Fusarium spp.* without killing the kernels. Drechsler (26) stated that preliminary treatments of badly discolored wheat seed with certain organic mercury compounds indicated control of seedling blight. Atanasoff and Johnson (4) have shown that *H. sativum* was practically eliminated from badly infested seeds of Chevalier barley by means of dry-heat treatment. They also were able to eliminate the wheat scab organism from several varieties of wheat in the same way. It will be recalled that the writer was unable to eliminate *H. sativum* completely from badly infected wheat and barley seed by the Jensen hot-water treatment.

EFFECT OF SEED TREATMENT ON GROWTH OF SEEDLINGS

It seems obvious that anything which stimulates the growth of seedlings would reduce the damage from the disease and vice versa. Numerous investigators have reported stimulation of seedling growth as a result of seed treatment. Mackie and Briggs (46) state that treatment of wheat seed with copper sulphate and formaldehyde represses growth, but that the application of copper carbonate dust to wheat seed results in vigorous seedlings. Stakman and Lambert (55), Heald and Smith (35), and others have reported stimulatory growth as the result of seed treatment.

In the present studies, observations were made on seedlings in the field and in the greenhouse to ascertain if seed treatment stimulated growth. The treatments and varieties of cereal used were the same as those used in the germination tests (Tables XLIII and XLIV).

None of the fungicidal dusts caused any appreciable stimulation of growth in the greenhouse. Several of the liquid compounds, especially Uspulun, Chlorophol, Tillantin, and silver nitrate, caused apparent stimulation, but the results were not conclusive. The stimulation was not always consistent in the different varieties and sometimes not even

in the two series of the same variety. This might be explained in part by the higher percentage of germination due to the treatment, and the consequent density of the stand. An increase in the percentage of germination would naturally decrease the amount of space per plant. On the other hand, copper sulphate, white Seed-O-San, and sulphur dust consistently retarded the growth of the wheat seedlings in the greenhouse, but not that of the barley. The plants in the plots treated with the last-named compounds, as well as the controls, appeared to be most severely attacked by root-rot. Within a month the basal portion of all the plants in the experiment became infected conspicuously with *Helminthosporium*. It will be recalled that the seeds were sown in *Helminthosporium*-sick soil obtained from the field.

Observations on the different treatments in the field were made over a period of two years. Each year the seed was sown in rod rows, each row being replicated four times. There was no conclusive evidence that fungicides stimulated or depressed seed germination and the rate of growth of the seedlings. Either the treatments were not effective, or the soil was so thoroly infested with *H. sativum* and other root-rotting organisms as to obscure the effect of seed treatment.

The writer's results, therefore, do not corroborate those of other investigators. The conditions of the experiments probably account for this fact. Undoubtedly the kind and variety of grain, soil conditions, and meteorological conditions affect results considerably.

EFFECT OF SEED TREATMENT ON DEVELOPMENT OF BASAL STEM-ROT AND ROOT-ROT

Seed treatment with dusts and liquid fungicides did not control secondary root-rot and basal stem-rot. In 1923 notes were taken on the amount of root-rot and basal stem-rot on 3 varieties of wheat and 3 of barley treated with the fungicides, except Germisan and Uspulun, listed in Table XLVI. In 1924 observations were made for all the 16 different treatments. The varieties were grown in quadruplicated rod rows. In neither season was there an appreciable difference in the amount of root-rot and basal stem-rot in the different plots. The slight variations which did occur were not consistent between the varieties, and the variation between the replicated rows was as great as that between any two treatments. The controls always were as free from disease as the plants in the treated plots.

TABLE XLVI

EFFECTIVENESS OF SEED TREATMENTS IN PREVENTING KILLING OF MONAD AND PENTAD WHEATS BY ROOT ROT AND BASAL STEM ROT, AND A STATISTICAL COMPARISON WITH THE CONTROLS

Treatment	Statistical data in comparison with check for									
	Monad, C.I. 3320					Pentad, C.I. 3322				
	Av. per cent killed*	M.D.	S.D.	Z	Odds	Av. per cent killed	M.D.	S.D.	Z	Odds
Dusts										
Check—none	72.2	...	...	...	...	77.0	...	...	...	...
Nickel carbonate, 4 oz. per bu.	69.5	2.75	6.01	.45	3.0	76.2	.75	1.29	.58	4.1
Copper sulphate and lime, 4 oz. per bu.	68.2	4.0	2.51	1.59	27.7	73.0	4.0	2.12	1.88	41.3
Copper carbonate, 4 oz. per bu.	73.5	—1.25	8.84	.13	1.4	72.2	4.75	3.23	1.38	19.6
Seed-O-San (pink) 3 oz. per bu.	72.0	0.25	4.96	.05	<1	66.0	11.0	6.20	1.77	35.5
Seed-O-San (white) 4 oz. per bu.	72.5	—0.25	7.69	.03	<1	70.8	6.25	6.58	.96	9.2
Sulphur dust, 4 oz. per bu.	71.0	1.25	4.65	.27	1.8	73.7	3.25	2.07	1.57	26.5
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	75.0	—2.75	2.56	1.07	11.0	68.5	8.5	3.27	2.61	98.0
Tillantin "C" 0.25% soaked 2 hrs. cold	75.5	—3.25	6.37	.50	3.4	74.0	3.0	4.74	.63	4.6
Semesan 0.3% cold soaked 2 hrs.	71.0	1.25	8.07	.15	1.4	74.5	2.5	4.21	.59	4.3
Silver nitrate cold n/100 soaked 2 hrs.	75.0	—2.75	6.41	.42	2.7	75.0	2.0	1.87	1.07	11.4
Germisan 0.25% soaked ½ hr. cold	73.7	—1.50	9.75	.15	1.4	73.0	4.0	6.67	.59	4.3
Germisan 0.25% cold soaked 1½ hrs.	79.7	—7.50	2.10	3.02	38.3	73.0	4.0	6.81	.58	4.0
Uspulun 0.25% cold soaked 1 hr.	70.7	1.50	7.12	.22	1.7	72.5	4.5	1.50	3.00	144.0
Uspulun 0.25% cold soaked 2 hrs.	73.0	—0.75	6.82	.10	1.2	71.2	5.75	2.38	2.41	78.5
Uspulun 0.25% soaked ½ hr. 40-45° C.	76.2	—4.0	1.64	2.44	80.9	65.2	11.75	3.02	3.89	299.0
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	76.5	—4.25	9.41	.45	3.0	69.7	7.25	6.64	1.09	11.9

* Average per cent of plants killed after heading, based on counting the number of plants in 4 replicated rod rows.

The percentage of Monad and Pentad wheat plants killed after heading in 1924 was determined by counting the total number of diseased and normal plants in the four replicated rod rows. The results of these counts are given in Table XLVI. The significance of these percentages was determined by "Student's Method" (64 and 65). The odds were obtained directly by looking up the value of Z in the table cited by Love (44) in the Journal of the American Society of Agronomy, Vol. 16, pp. 70-71, 1924. Certainly none of the treatments decreased or increased the percentage of Monad plants killed as compared with the controls. For Pentad, however, odds as high as 299 to 1 were secured in favor of treatment with Uspulun (soaked one half hour at 45° to 50° C.). In five treatments the odds were greater than 30 to 1 in favor of the treatments, but, owing to the lack of consistency between the two varieties of wheat, the results can not be considered conclusive.

EFFECT OF SEED TREATMENT ON YIELDS

In order to determine whether seed treatment would increase yields in the absence of smut, the following experiment was made. Three varieties of wheat—Marquis, Monad, and Pentad—and three varieties of barley—Manchuria, Lion, and Svansota—were treated as indicated in Tables XLVII and XLVIII and sown in *Helminthosporium*-sick soil. All fungicides except Germisan and Uspulun were used in both 1923 and 1924. Yield data were obtained from four systematically replicated rod rows (Tables XLVII and XLVIII). In general, seed treatment did not increase yields. In only 1 test out of 152 were the odds 30 to 1 or greater that the treatment increased yield. In 9 tests they were 30 to 1 or greater that the treatment had decreased the yield. The significance of the results was determined by "Student's Method." In the remaining 142 tests the results were not statistically significant. It is doubtful, therefore, whether the seed treatments used increased yields by decreasing the amount of infection by *H. sativum*.

TABLE XLVII

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF BARLEY GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Manchuria (Minn. No. 184)									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	34.8	...	...	...	...	37.6	...	...	...	...
Nickel carbonate, 4 oz. per bu.	32.8	—2.0	8.88	0.23	1.8	34.1	—3.52	3.44	1.02	10.0
Copper sulphate and lime, 4 oz. per bu.	28.3	—6.5	3.89	2.25	65.2	34.5	—3.05	3.50	0.87	7.4
Copper carbonate, 4 oz. per bu.	32.4	—2.35	4.99	0.47	3.0	36.6	—1.00	3.32	0.30	2.1
Seed O-San (pink) 3 oz. per bu.	29.1	—5.65	2.46	1.63	29.8	37.9	0.35	3.0	0.11	<1.0
Seed-O-San (white) 4 oz. per bu.	36.0	1.2	12.45	0.08	<1.0	35.6	—1.90	2.80	6.80	5.4
Sulphur dust, 4 oz. per bu.	36.3	1.5	1.46	1.03	11.0	39.0	1.43	3.38	0.42	2.7
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	29.4	—5.4	6.32	0.85	7.4	42.4	4.80	3.33	1.45	21.9
Tillantin "C" 0.25% soaked 2 hrs. cold	21.9	—12.9	7.39	1.74	34.5	37.1	—0.45	4.89	0.09	<1.0
Semesan 0.3% soaked 2 hrs. cold	30.5	—4.3	3.50	1.23	15.7	32.9	—4.72	6.19	0.77	5.9
Silver nitrate cold n/100 soaked 2 hrs.	31.0	—3.8	9.89	0.38	2.7	35.9	—1.72	3.46	0.49	3.4
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	34.6	—3.00	4.94	0.60	4.3
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	34.3	—3.32	1.86	2.51	86.7
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	..	34.9	—2.75	5.79	0.47	3.0
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	35.2	—2.40	3.80	0.64	4.8
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	38.0	0.40	5.04	0.07	<1.0
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	39.7	2.10	8.13	0.26	1.8

* Average for four systematically replicated rod rows.

TABLE XLVII—*Continued*

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF BARLEY GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Lion, C. I. 923									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	24.6	...	...	...	...	70.3	...	...	...	...
Nickel carbonate, 4 oz. per bu.	23.1	—1.55	2.16	0.71	5.4	69.5	—0.8	5.24	0.15	1.4
Copper sulphate and lime, 4 oz. per bu.	20.9	—3.65	5.29	0.68	5.4	68.2	—2.15	7.55	0.28	2.1
Copper carbonate, 4 oz. per bu.	24.4	—0.20	5.83	0.03	<1.0	67.5	—2.8	10.14	0.27	1.8
Seed-O-San (pink) 3 oz. per bu.	19.2	—5.40	3.46	1.56	25.7	69.6	—0.7	6.12	0.01	<1.0
Seed-O-San (white) 4 oz. per bu.	23.1	—1.50	5.90	0.27	1.8	59.5	—11.9	12.6	0.94	9.0
Sulphur dust, 4 oz. per bu.	23.4	—1.20	4.66	0.25	1.8	67.1	—3.2	7.43	0.43	3.0
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	22.4	—1.95	4.03	0.48	3.4	66.1	—4.2	4.9	0.86	7.3
Tillantin "C" 0.25% soaked 2 hrs. cold	21.2	—3.40	4.83	0.70	5.4	59.9	—10.5	15.6	0.60	4.3
Semesan 0.3% soaked 2 hrs. cold	25.4	0.85	4.64	0.18	1.6	65.7	—4.6	6.12	0.75	5.9
Silver nitrate cold n/100 soaked 2 hrs.	20.7	—3.95	7.34	0.54	3.8	60.0	—10.3	9.69	1.06	11.0
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	64.3	—6.05	13.3	0.45	3.0
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	59.6	—10.8	9.5	1.14	13.2
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	...	65.1	—5.2	4.23	1.22	14.5
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	70.6	0.25	3.9	0.06	<1.0
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	72.9	2.55	3.2	0.80	6.7
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	67.4	—2.9	4.2	0.69	5.4

* Average for four systematically replicated rod rows.

TABLE XLVII—*Concluded*

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF BARLEY GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Svansota (Minn. No. 440)									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	33.2	...	...	...	...	39.6	...	...	...	...
Nickel carbonate, 4 oz. per bu.	30.1	—3.05	2.98	1.02	10.0	36.5	—3.07	6.2	0.49	3.4
Copper sulphate and lime, 4 oz. per bu.	26.1	—7.1	6.66	1.66	29.8	30.3	—9.35	6.32	1.48	23.9
Copper carbonate, 4 oz. per bu.	27.9	—5.3	2.82	1.88	42.5	38.6	—1.0	7.55	0.13	1.4
Seed-O-San (pink) 3 oz. per bu.	24.3	—8.95	6.89	1.29	17.2	37.0	—2.55	7.61	0.33	2.4
Seed-O-San (white) 4 oz. per bu.	...	...	...	...	...	37.3	—2.35	3.66	0.64	4.8
Sulphur dust, 4 oz. per bu.	...	...	...	...	...	37.9	—1.65	4.08	0.40	2.7
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	29.0	—4.22	7.72	0.55	3.8	38.3	—1.30	2.61	0.50	3.4
Tillantin "C" 0.25% soaked 2 hrs. cold	24.4	—8.8	4.04	2.18	61.9	36.7	—2.87	4.77	0.60	4.3
Semesan 0.3% soaked 2 hrs. cold	...	...	..	...	...	36.0	—3.62	5.01	0.72	5.4
Silver nitrate cold n/100 soaked 2 hrs.	...	...	...	...	...	37.6	—1.97	5.35	0.36	2.4
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	37.7	—1.92	7.86	0.22	1.6
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	37.7	—1.90	4.50	0.42	2.7
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	...	37.2	—2.40	2.23	1.02	10.0
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	39.8	.12	3.30	0.03	1.0
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	41.4	1.82	5.83	0.31	2.1
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	35.2	—4.40	10.48	0.42	2.7

* Average for four systematically replicated rod rows.

TABLE XLVIII

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF WHEAT GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Marquis, C. I. 3641									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	22.8	...	...	...	...	26.8	...	...	...	...
Nickel carbonate, 4 oz. per bu.	23.6	0.83	2.73	0.30	2.1	27.4	0.25	2.37	0.10	1.3
Copper sulphate and lime, 4 oz. per bu.	21.5	—1.25	1.31	.96	9.0	24.6	—2.20	1.21	1.91	42.7
Copper carbonate, 4 oz. per bu.	21.1	—1.68	3.39	.49	3.4	24.9	—1.90	2.06	0.92	8.2
Seed-O-San (pink) 3 oz. per bu.	25.0	2.25	5.69	.39	2.7	27.2	0.4	3.15	0.12	1.3
Seed-O-San (white) 4 oz. per bu.	22.7	—0.07	3.76	.01	<1.0	25.4	—1.4	3.46	0.40	2.7
Sulphur dust, 4 oz. per bu.	21.9	—0.90	2.03	.44	3.0	24.8	—2.0	.54	3.70	260.0
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	24.2	1.40	4.03	.33	2.4	25.4	—1.4	2.64	0.53	3.8
Tillantin "C" 0.25% soaked 2 hrs. cold	23.4	0.63	3.30	.19	1.6	26.6	—0.2	1.17	0.17	1.4
Semesan 0.3% soaked 2 hrs. cold	25.0	2.4	1.03	2.33	73.1	26.9	0.1	2.39	0.04	<1.0
Silver nitrate cold n/100 soaked 2 hrs.	22.0	—0.75	2.61	0.28	2.1	26.0	—0.8	3.12	0.25	1.8
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	27.3	0.55	4.97	0.11	1.3
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	28.8	2.0	4.91	0.40	2.7
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	...	25.8	—1.0	4.92	0.20	1.6
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	26.3	—0.55	5.43	0.10	1.3
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	32.1	5.30	9.08	0.58	4.3
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	28.7	1.90	6.35	0.29	2.1

* Average for four systematically replicated rod rows.

TABLE XLVIII—*Continued*

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF WHEAT GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Monad, C. I. 3320									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	17.0	...	...	...	...	14.1	...	...	...	...
Nickel carbonate, 4 oz. per bu.	18.4	1.35	4.37	0.38	2.7	13.9	—0.15	5.00	0.03	<1.0
Copper sulphate and lime, 4 oz. per bu.	16.2	—0.8	4.74	.17	1.4	17.1	3.0	3.40	0.88	8.2
Copper carbonate, 4 oz. per bu.	15.4	—1.6	6.01	.26	1.9	16.5	2.4	4.05	0.59	4.3
Seed-O-San (pink) 3 oz. per bu.	17.3	0.33	6.70	.04	<1.0	15.7	1.6	1.52	1.05	11.0
Seed-O-San (white) 4 oz. per bu.	15.7	—1.25	7.93	.16	1.4	13.8	—0.30	5.22	0.05	<1.0
Sulphur dust, 4 oz. per bu.	14.8	—2.20	3.45	.63	4.8	14.1	0.02	2.91	0.00	<1.0
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	19.8	2.80	2.93	.95	9.0	14.4	0.32	3.86	0.08	<1.0
Tillantin "C" 0.25% soaked 2 hrs. cold	17.4	0.38	6.55	.05	<1.0	13.1	—1.02	3.98	0.24	1.8
Semesan 0.3% soaked 2 hrs. cold	17.0	—0.02	4.84	.00	<1.0	14.9	0.85	2.07	0.41	2.7
Silver nitrate cold n/100 soaked 2 hrs.	16.7	—0.30	4.78	0.06	<1.0	13.7	—0.4	4.01	0.09	<1.0
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	11.7	—2.35	3.94	0.62	4.3
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	15.4	1.35	3.61	0.37	2.4
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	...	14.0	—0.10	3.43	0.03	<1.0
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	15.8	1.70	6.79	0.25	1.8
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	16.1	2.0	3.63	0.59	4.3
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	14.8	0.75	3.99	0.19	1.6

* Average for four systematically replicated rod rows.

TABLE XLVIII—*Concluded*

EFFECT OF VARIOUS FUNGICIDES ON YIELD OF WHEAT GROWN ON *Helminthosporium*-SICK SOIL AT UNIVERSITY FARM, ST. PAUL, IN 1923 AND 1924

Treatment	Pentad, C. I. 3322									
	1923					1924				
	Av. yield, bu.*	M.D.	S.D.	Z	Odds	Av. yield, bu.*	M.D.	S.D.	Z	Odds
Dusts										
Check—none	19.9	...	...	...	...	20.7	...	...	...	...
Nickel carbonate, 4 oz. per bu.	18.7	—1.15	3.44	0.33	2.4	19.7	—1.05	3.46	0.30	2.1
Copper sulphate and lime, 4 oz. per bu.	19.9	0.0	2.58	0.0	<1.0	21.4	0.70	2.30	.30	2.1
Copper carbonate, 4 oz. per bu.	22.3	2.45	2.29	1.07	11.0	20.5	—0.18	9.50	.01	<1.0
Seed-O-San (pink) 3 oz. per bu.	20.8†	2.30	1.93	1.19†	7.1†	22.3	1.60	3.49	.46	3.0
Seed-O-San (white) 4 oz. per bu.	19.6	—0.23	5.73	0.04	<1.0	23.2	2.50	3.80	.66	4.8
Sulphur dust, 4 oz. per bu.	22.1	2.20	3.84	0.58	4.3	21.4	0.72	3.10	.23	1.8
Liquids										
Chlorophol 0.25% soaked 2 hrs. cold	20.2	0.39	5.91	0.06	<1.0	23.7	—3.0	3.88	.72	5.4
Tillantin "C" 0.25% soaked 2 hrs. cold	20.3	0.45	2.08	0.21	1.6	19.2	—1.45	3.41	.42	2.7
Semesan 0.3% soaked 2 hrs. cold	18.9	—0.85	3.20	0.25	1.8	21.4	0.70	3.99	.17	1.4
Silver nitrate cold n/100 soaked 2 hrs.	17.5	—2.45	1.28	1.91	42.5	20.5	—0.23	1.24	.18	1.6
Germisan 0.25% soaked ½ hr. cold	...	...	...	...	...	21.4	0.72	4.13	.17	1.4
Germisan 0.25% soaked 1½ hrs. cold	...	...	...	...	...	21.8	1.1	4.81	.22	1.6
Uspulun 0.25% soaked 1 hr. cold	...	...	...	...	...	23.4	2.65	5.01	.52	3.4
Uspulun 0.25% soaked 2 hrs. cold	...	...	...	...	...	19.2	—1.45	4.38	.30	2.1
Uspulun 0.25% soaked ½ hr. 40-45° C.	...	...	...	...	...	22.3	1.58	2.36	.67	4.8
Uspulun 0.25% soaked 1½ hrs. 40-45° C.	...	...	...	...	...	20.8	0.05	2.57	0.01	<1.0

* Average for four systematically replicated rod rows.

† Only three replicated rod rows.

VARIETAL RESISTANCE

The study of varietal resistance is of paramount importance, since the disease can not be effectively controlled by seed treatment or cultural practices. In 1921 Hayes and Stakman (32) demonstrated that there were great differences between the resistance of barley varieties and purified hybrids to *H. sativum*. They concluded that there was no apparent correlation between botanical characters and resistance. In 1923 Hayes, Stakman, et al. (33) verified and extended these results. They obtained a white, resistant, smooth-awned barley from a cross between a black smooth-awned, susceptible and a resistant, rough-awned, six-rowed barley. They showed that the four species of *Hordeum—H. vulgare, H. intermedium, H. distichum,* and *H. deficiens*—contain varieties susceptible to *Helminthosporium*. All the species except *H. intermedium* also contained resistant varieties. Griffee (30) crossed Svansota and Lion and showed that there was partial linkage between white, two-rowed, rough-awned, and resistance factors. His results indicate that at least three factors or groups of factors were involved in determining the mode of inheritance of resistance or susceptibility.

Stakman (60), in 1919, was the first to report varietal differences in susceptibility to *Helminthosporium* in wheat. Aamodt (1) noted that in a cross between Marquis, a susceptible host, and Kanred, a moderately resistant variety, spring varieties with a high degree of resistance to root-rot were obtained. Christensen (18) observed varietal differences in susceptibility to root-rot in greenhouse tests. Stakman, Lambert, and Flor (56) reported variation in susceptibility for different species groups of wheat. Christensen and Stakman (20) recently called attention to the great susceptibility of durums to basal stem-rot.

Practically no work has been done on varietal resistance of wheat to *H. sativum*. For this reason, a preliminary survey of varietal susceptibility was made. The varieties used were obtained from the Office of Cereal Investigations, United States Department of Agriculture. For field tests, seven-foot rows were sown at the rate of six and a half grams of seed per row. At University Farm, St. Paul, the seed was sown in root-rot-sick soil. At Coon Creek, Minn., as well as at University Farm, the soil was inoculated on the date of seeding. The inoculum was grown on sterilized wheat and oat kernels and this was applied to the open rows before covering them. In 1923 a single row of each variety was grown at Coon Creek and at University Farm, while in 1924 duplicated rows were sown at both places. In both years notes were taken on the degree of root- and basal stem-rot and severity of seed blighting. In 1924 notes were also taken on the percentage

of plants killed after heading. As previously mentioned, the degree of infection for the purpose of exact comparison is designated by numerical figures. High figures, of which 13 is the maximum, denote complete susceptibility; while 1 signifies minimum infection observed. The results are presented in Table XLIX.

All varieties of *Triticum vulgare—T. compactum, T. durum, T. dicoccum, T. turgidum, T. spelta,* and *T. polonicum*—became infected with root- and basal stem-rot to a greater or lesser degree. The club wheats as a group appeared to be the most resistant, altho this apparent resistance may be due to late maturity. The durums were the most susceptible. There were striking differences in varietal susceptibility among the 73 varieties of common wheat, altho in general they were much more resistant than the durums. Only 2 varieties of *Triticum turgidum* were sown: Clackamas, C. I. 6241; and Alaska, C. I. 5988. The former was extremely susceptible to root-rot, the latter moderately so.

In general, the varieties which were resistant to root- and basal stem-rot at University Farm were resistant also at Coon Creek. Likewise, the varieties susceptible or resistant one year tended to be respectively susceptible or resistant the next year.

The results summarized in Tables L and LI show a close correlation between the behavior of two different series of wheat varieties to root-rot and basal stem-rot grown at Coon Creek and at University Farm. The coefficients were respectively $+0.6829 \pm 0.0352$ and $+0.4856 \pm 0.0505$.

Positive correlations were likewise obtained between the behavior of the varieties to root- and basal stem-rot at Coon Creek and University Farm in 1923 and 1924, and between the averages for the two years for the two localities.

The data are given in Tables LII to LIV inclusive. The results were respectively $+0.5123 \pm 0.0493$, $+0.4781 \pm 0.0512$, and $+0.4367 \pm 0.0557$. These coefficients indicate that susceptibility of wheat varieties to root- and basal stem-rot are inherited characters and not variations due to fluctuations in environmental conditions.

In order to determine whether differences in percentage of killing in 1924 were due to genetic or to ecological factors, the bahavior of each variety in duplicate series was studied. The plants were grouped into classes, each class consisting of a 10 per cent range. A correlation coefficient of $+0.9760 \pm 0.0031$ was obtained, showing a practical identity in the reaction of each variety to basal stem-rot in the two series, thus again indicating that resistance to this malady is apparently a genetic character.

TABLE XLIX

DEGREE OF ROOT- AND BASAL STEM-ROT, AND SEED BLIGHT OF 105 VARIETIES OF WHEAT GROWN ON SANDY SOIL AT COON CREEK AND ON HEAVY SOIL AT UNIVERSITY FARM IN 1923 AND 1924

Species and varieties	C. I. No.	Degree of infection*: Root- and basal stem-rot: 1923: Univ. Farm	1923: Coon Creek	1923: Av.	1924: Univ. Farm: Ser. A	1924: Univ. Farm: Ser. B	1924: Univ. Farm: Av.	1924: Coon Creek: Ser. A	1924: Coon Creek: Ser. B	1924: Coon Creek: Av.	1924: Av. for two stations	Seed infection: 1923: Univ. Farm	1923: Coon Creek	1924: Univ. Farm	1924: Coon Creek	Percentage killed after heading: 1924: Univ. Farm: Ser. A	Univ. Farm: Ser. B	Univ. Farm: Av.
Triticum vulgare																		
Early Defiance	6480	6	10	8	8	5	7	7	10	9	8	4	1	1	1	8	5	6.5
Colorado No. 50	4959	7	11	9	8	7	8	7	8	8	8	10	8	2	1	11	18	14.5
Touse	6047	5	9	7	6	6	6	6	7	7	7	3	3	2	1	17	16	16.5
Defiance	6477	7	7	7	7	7	7	6	9	8	8	1	2	2	1	8	13	10.5
Rink	5868	6	10	8	6	7	7	5	6	6	7	3	3	1	1	8	7	7.5
Bunyip	5125	7	10	8	6	6	6	5	7	6	6	2	4	3	1	23	20	21.5
Pacific Bluestem	4067	7	5	6	6	6	6	5	6	6	6	1	..	2	1	15	11	13.0
Mexican Bluestem	6004	7	8	8	8	6	7	6	6	6	7	3	1	3	1	20	29	24.5
Dart	5128	7	9	8	8	6	7	6	7	7	7	3	..	1	1	6	13	9.5
Gypsum	4762	8	10	9	6	7	7	6	7	7	7	7	4	2	1	12	15	13.5
Surprise	2986	8	10	9	6	6	6	6	7	7	7	3	4	2	1	17	15	16.0
Dicklow	3663	8	10	9	9	9	9	6	7	7	8	3	3	1	2	22	16	19.0
Quality	6157	7	10	8	9	8	9	8	10	9	9	5	3	2	2	8	6	7.0
Bobs	4991	9	12	11	9	6	8	7	6	7	8	8	5	1	1	12	19	15.5
White Fife	4412	7	10	8	5	5	5	8	7	8	7	1	1	3	1	3	3	3.0
White Federation	4981	8	10	9	6	7	7	7	6	7	7	5	7	1	1	5	23	14.0
Lynn	6346	8	8	8	6	6	6	8	7	8	7	9	7	1	1	6	6	6.0
Regenerated Defiance	3703	6	9	8	5	5	5	7	6	7	6	2	1	3	1	2	3	2.5
New Zealand	6011	6	6	6	6	7	7	6	6	6	7	2	1	2	1	7	2	4.5
Pilcraw	5540	6	9	8	8	7	8	6	6	6	7	1	1	1	1	14	11	12.5
Kinney	5189	5	5	5	5	3	4	5	9	7	6	3	..	2	1	8	10	9.0
Purple Straw	1915	5	8	7	5	5	5	5	7	6	6	1	..	1	1	17	14	15.5
Huston	5208	6	7	7	6	7	7	7	8	8	8	4	3	3	..	5	9	6.5

* Symbols of infection—0=Absence of infection, 1=Trace−, 2=Trace, 3=Trace+, 4=Light−, 5=Light, 6=Light+, 7=Moderate−, 8=Moderate, 9=Moderate+, 10=Heavy−, 11=Heavy, 12=Heavy+.

TABLE XLIX—*Continued*

DEGREE OF ROOT- AND BASAL STEM-ROT, AND SEED BLIGHT OF 105 VARIETIES OF WHEAT GROWN ON SANDY SOIL AT COON CREEK AND ON HEAVY SOIL AT UNIVERSITY FARM IN 1923 AND 1924

Species and varieties	C. I. No.	Degree of infection*													Percentage killed after heading			
		Root- and basal stem-rot									Seed infection							
		1923			1924						1923		1924		1924			
					Univ. Farm			Coon Creek							Univ. Farm			
		Univ. Farm	Coon Creek	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.	Av. for two stations	Univ. Farm	Coon Creek	Univ. Farm	Coon Creek	Ser. A	Ser. B	Av.
Red Bobs	6255	7	11	9	8	7	8	7	7	7	8	1	2	1	1	10	13	11.5
Marquis	3641	5	11	8	6	9	8	5	8	7	8	3	4	1	1	6	7	6.5
Red Fife	3329	6	8	7	6	8	7	5	8	7	7	1	1	1	1	8	11	9.5
Power	3697	7	10	9	6	6	6	5	8	7	7	1	1	3	1	6	8	7.0
Glyndon	2870	8	10	9	6	7	7	7	7	7	7	2	2	1	1	6	6	6.0
Rysting	3022	8	9	9	6	6	6	5	7	6	6	1	5	3	1	8	5	6.5
Wellman	4144	7	8	8	7	7	7	5	7	6	7	5	3	3	1	9	10	9.5
Early Red Fife	4932	8	9	9	6	7	7	6	7	7	7	1	4	1	1	5	11	8.0
Ghirka	1517	8	8	8	5	6	6	6	7	7	7	3	2	1	1	5	2	3.5
Ruby	6047	9	11	10	9	8	9	7	7	7	7	5	1	2	1	4	3	3.5
Kitchener	4800	7	9	8	7	7	7	6	7	7	7	2	1	2	1	19	15	17.0
John Brown	4121	7	8	8	8	6	7	8	8	8	8	3	3	2	1	10	8	9.0
Allen	5407	6	7	7	7	7	7	7	7	7	7	3	3	4	1	10	8	9.0
Federation	4734	4	7	6	7	9	8	7	7	7	8	2	2	1	1	27	18	22.5
Foisy	5242	5	6	6	7	6	7	5	5	5	6	3	3	6	1	8	8	8.0
Schlanstedt	4646	4	5	5	6	5	6	5	6	6	6	1	..	1	..	5	3	4.0
Hard Federation	4980	7	11	9	10	9	10	10	9	9	10	8	4	1	1	24	24	24.0
Resaca	6390	7	5	6	7	8	8	5	6	6	7	1	..	1	2	3	4	3.5
Stanley	4796	6	9	8	7	6	7	6	6	6	7	1	1	1	1	17	7	12.0
Jumbuck	4608	6	9	8	9	8	9	6	7	7	8	5	..	2	1	22	14	18.0
Indian	4489	9	11	10	7	7	7	7	8	8	8	5	8	3	1	11	9	10.0
Haynes Bluestem	2874	3	8	6	8	6	7	5	6	6	7	3	1	2	1	11	9	10.0
Dakota	3083	7	7	7	6	6	6	6	6	6	6	1	..	1	1	6	8	7.0
Galgalos	2398	9	10	10	7	8	8	7	8	8	8	2	2	2	1	20	14	17.0

* Symbols of infection—0=Absence of infection, 1=Trace—, 2=Trace, 3=Trace+, 4=Light—, 5=Light, 6=Light+, 7=Moderate—, 8=Moderate, 9=Moderate+, 10=Heavy—, 11=Heavy, 12=Heavy+.

TABLE XLIX—*Continued*

DECREASE OF ROOT- AND BASAL STEM-ROT, AND SEED BLIGHT OF 105 VARIETIES OF WHEAT GROWN ON SANDY SOIL AT COON CREEK AND ON HEAVY SOIL AT UNIVERSITY FARM IN 1923 AND 1924

Species and varieties	C. I. No.	Degree of infection*																
		Root- and basal stem-rot										Seed infection				Percentage killed after heading		
		1923			1924							1923		1924		1924		
					Univ. Farm			Coon Creek			Av. for two stations					Univ. Farm		
		Univ. Farm	Coon Creek	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.		Univ. Farm	Coon Creek	Univ. Farm	Coon Creek	Ser. A	Ser. B	Av.
Sonora	3036	9	12	11	5	8	7	7	8	8	8	8	6	2	1	11	9	10.0
Palisade	4798	6	9	8	7	7	7	9	7	8	8	3	1	1	1	17	10	13.5
Propo	1970	7	9	8	8	6	7	7	10	9	8	3	3	1	1	14	9	11.5
Baart	1697	8	11	10	9	8	9	7	6	7	8	4	1	3	..	30	14	22.0
Talimka	2495	9	12	11	10	8	9	10	10	10	10	3	3	6	1	8	6	7.0
Champlain	4782	6	10	8	6	9	8	7	7	7	8	1	2	..	1	7	7	7.0
Java	4966	7	12	10	9	8	9	7	10	9	9	3	1	1	1	12	20	16.0
Erivan	2397	9	12	11	10	8	9	8	10	9	9	6	2	1	1	4	3	3.5
Converse	4141	6	9	8	7	6	7	7	10	9	8	4	1	1	1	5	11	8.0
Preston	3328	7	9	8	6	6	6	5	7	6	6	3	1	1	1	3	6	4.5
Kota	5878	7	10	9	7	5	6	7	7	7	7	2	2	1	1	3	3	3.0
Pioneer	4324	8	11	10	8	6	7	9	10	10	9	4	2	1	1	5	4	4.5
Fretes	1596	6	8	7	6	6	6	6	8	7	7	6	3	2	1	8	10	9.0
Dixon	6049	7	7	8	5	5	5	6	6	6	6	1	2	1	1	7	10	8.5
Chul	2227	7	12	10	7	8	8	8	8	8	8	7	8	2	3	3	5	4.0
Emerald	4397	7	7	7	8	9	9	6	6	6	8	3	4	1	..	10	16	13.0
Canadian Red	6282	7	7	7	10	9	10	7	7	7	9	5	5	6	1	7	15	11.0
Sevier	6247	8	6	7	6	6	6	5	6	6	6	2	1	5	1	11	7	9.0
Huron	3315	7	8	8	6	5	6	6	7	7	7	1	1	1	1	3	12	7.5
Norka	4377	6	8	7	6	6	6	7	7	7	7	1	1	2	1	5	7	6.0
Ladoga	4795	6	7	7	6	5	6	7	7	7	7	2	1	2	1	3	6	4.5
Laramie	6235	6	5	6	8	6	7	8	7	7	7	2	1	1	1	4	5	4.5
Prelude	4323	10	8	9	10	9	10	9	9	9	10	1	1	2	1	3	7	5.0

* Symbols of infection—0=Absence of infection, 1=Trace−, 2=Trace, 3=Trace+, 4=Light−, 5=Light, 6=Light+, 7=Moderate−, 8=Moderate, 9=Moderate+, 10=Heavy−, 11=Heavy, 12=Heavy+.

TABLE XLIX—*Continued*

DEGREE OF ROOT- AND BASAL STEM-ROT, AND SEED BLIGHT OF 105 VARIETIES OF WHEAT GROWN ON SANDY SOIL AT COON CREEK AND ON HEAVY SOIL AT UNIVERSITY FARM IN 1923 AND 1924

Species and varieties	C. I. No.	Degree of infection*													Percentage killed after heading			
		Root- and basal stem-rot										Seed infection						
		1923			1924							1923		1924		1924		
					Univ. Farm			Coon Creek			Av. for two stations					Univ. Farm		
		Univ. Farm	Coon Creek	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.		Univ. Farm	Coon Creek	Univ. Farm	Coon Creek	Ser. A	Ser. B	Av.
Humpback	3690	7	7	7	6	7	7	5	6	6	7	1	2	1	1	9	6	7.5
Marquis × Iumillo	II-15-44	8	..	..	10	7	9	7	8	8	9	2	..	1	1	13	18	15.5
Marquis × Kanred	II-15-57	8	..	..	7	6	7	7	7	7	7	2	..	1	1	6	5	5.5
Average																9.9	10.1	10.0
Triticum compactum																		
Little Club	4066	6	6	6	7	7	7	6	8	7	7	2	1	3	1	11	14	12.5
Big Club	4257	7	6	7	7	7	7	7	8	8	8	1	1	3	1	10	9	9.5
Hybrid 143	4160	5	5	5	9	7	8	5	8	7	8	1	..	2	..	12	15	13.5
Hybrid 63	4570	5	5	5	6	7	7	6	7	7	7	3	..	1	2	3	3	3.0
Hybrid 108	5025	5	5	5	6	7	7	6	7	7	7	1	..	1	1	4	4	4.0
Hybrid 123	4511	5	6	6	6	6	6	5	6	6	6	1	..	1	..	7	3	5.0
Jenkin	5177	6	6	6	5	6	6	6	7	7	7	1	..	2	..	7	6	6.5
Redchaff	4241	5	7	6	8	9	9	6	7	7	8	1	..	3	1	5	8	6.5
Bluechaff	5256	5	6	6	8	7	8	6	7	7	8	1	..	2	1	8	8	8.0
Dale	4155	5	6	6	8	7	8	5	8	7	8	1	..	1	1	5	4	4.5
Wilbur	6796	6	8	7	8	8	8	10	9	10	9	8	..	3	2	5	5	5.0
Mayview	5874	7	6	7	9	9	9	6	7	7	8	1	..	1	1	11	4	7.5
Average																7.3	6.9	7.1
Triticum turgidum																		
Clackamas	6241	6	9	8	12	12	12	8	10	9	11	6	..	..	3	87	90	88.5
Alaska	5988	8	6	7	9	7	8	8	10	9	9	1	..	2	3	15	16	15.5
Average																51.0	53.0	52.0

* Symbols of infection—0=Absence of infection, 1=Trace−, 2=Trace, 3=Trace+, 4=Light−, 5=Light, 6=Light+, 7=Moderate−, 8=Moderate, 9=Moderate+, 10=Heavy−, 11=Heavy, 12=Heavy+.

TABLE XLIV—*Continued*

DEGREE OF ROOT- AND BASAL STEM-ROT, AND SEED BLIGHT OF 105 VARIETIES OF WHEAT GROWN ON SANDY SOIL AT COON CREEK AND ON HEAVY SOIL AT UNIVERSITY FARM IN 1923 AND 1924

Species and varieties	C. I. No.	Degree of infection*																
		Root- and basal stem-rot										Seed infection				Percentage killed after heading		
		1923			1924							1923		1924		1924		
					Univ. Farm			Coon Creek			Av. for two stations					Univ. Farm		
		Univ. Farm	Coon Creek	Av.	Ser. A	Ser. B	Av.	Ser. A	Ser. B	Av.		Univ. Farm	Coon Creek	Univ. Farm	Coon Creek	Ser. A	Ser. B	Av.
Triticum durum																		
Pentad	3322	9	9	9	11	8	10	9	9	9	10	9	10	3	3	86	74	80.0
Peliss	1584	8	9	9	10	9	10	9	9	9	10	10	7	2	3	83	90	86.5
Acme	5284	9	9	9	10	9	10	9	10	10	10	7	3	6	2	84	87	85.5
Monad	3320	9	9	9	12	9	11	9	9	9	10	5	9	3	2	80	79	79.5
Arnautka	1494	5	5	5	10	9	10	7	9	8	9	4	..	4	2	84	78	81.0
Mindum	5296	9	7	8	11	10	11	7	8	8	10	7	2	6	2	93	90	91.5
Kubanka	1440	9	6	8	11	10	11	9	8	9	10	5	9	3	2	89	74	81.5
Kubanka No. 8	4063	9	9	9	10	10	10	9	7	8	9	5	7	3	2	78	71	74.5
Buford	5295	8	10	9	11	8	10	9	8	9	10	5	7	3	1	82	83	82.5
Marcuani	1593	9	11	10	12	9	11	8	10	9	10	7	8	2	3	82	88	85.0
Velvet Don	2222	8	10	9	11	9	10	7	10	9	10	4	8	1	..	89	90	89.5
Golden Ball	6227	7	10	9	11	12	12	7	7	7	10	11	9	1	1	88	98	93.0
Kahla	5529	7	9	8	10	13	12	7	7	7	10	4	6	6	1	83	82	82.5
Iumillo selection		11	..	..	9	9	9	8	8	8	9	8	..	2	1	21	26	23.5
Average																80.1	79.3	79.7
Triticum dicoccum																		
Khapli	4013	11	13	12	12	12	12	10	11	11	12	4	1	2	1	..	..	...
Vernal	1524	5	7	6	12	7	10	6	8	7	9	1	1	1	1	20	13	16.5
Triticum spelta																		
White Spring	1775	6	6	6	9	5	7	5	9	7	7	1	..	1	1	24	16	20.0
Triticum polonicum																		
White Polish	3007	10	9	10	11	11	11	7	7	7	9	3	..	3	1	11	33	22.0
Average for total varieties																20.1	20.2	20.2

* Symbols of infection—0=Absence of infection, 1=Trace—, 2=Trace, 3=Trace+, 4=Light—, 5=Light, 6=Light+, 7=Moderate—, 8=Moderate, 9=Moderate+, 10=Heavy—, 11=Heavy, 12=Heavy+.

TABLE L

CORRELATION BETWEEN DEGREE OF ROOT-ROT AND BASAL STEM-ROT IN 105 VARIETIES OF WHEAT GROWN IN TWO DIFFERENT SERIES AT UNIVERSITY FARM IN 1924

Degree of infection in Series I	Degree of infection in Series II: 3	4	5	6	7	8	9	10	11	12	13	
5	1		4	2		1						8
6			3	13	10	1	2					29
7			1	4	8	3	1					17
8			1	7	5	1	2					16
9			1	1	2	5	3					12
10					1	2	6	1			1	11
11						2	1	2	1	1		7
12					1		2			2		5
	1	0	10	27	27	15	17	3	1	3	1	105

$r = +.6829 \pm .0352$

TABLE LI

CORRELATION BETWEEN DEGREE OF ROOT-ROT AND BASAL STEM-ROT OF 105 VARIETIES OF WHEAT GROWN IN TWO DIFFERENT SERIES AT COON CREEK IN 1924

Degree of infection in Series I	Degree of infection in Series II: 5	6	7	8	9	10	11	
5	1	8	5	5	2			21
6		7	16	3	1			27
7		6	12	8	1	5		32
8			3	2		5		11
9			2	3	3	2		10
10			1		1	1	1	4
	1	22	39	21	8	13	1	105

$r = +.4856 \pm .0505$

An attempt was made to determine whether a correlation existed between the average percentage of plants killed in 1924 and the average degree of root- and basal stem-rot on 101 varieties of wheat grown at Coon Creek and University Farm in 1923. A correlation coefficient of $+0.4015 \pm 0.0560$ was obtained, which seems to show that such correlation possibly exists.

In both years separate notes were taken on the degree of discoloration of the seed. The results are presented in Table XLIX. There was considerable variation in degree of susceptibility between different varieties and species. The durums as a group were the most susceptible

varieties. In 1923 a correlation coefficient was computed for the degree of seed infection for 79 varieties of wheat grown at University Farm and at Coon Creek (Table LV). The correlation was $+0.6738 \pm 0.0414$. For the same year the correlation coefficient for seed infection of 102 varieties at University Farm as related to severity of basal stem-rot and root-rot was $+0.4015 \pm 0.0560$ (Table LVI). Thus the degree of seed infection appears to be related to varietal susceptibility and is also correlated with root infection. Seed discoloration may be used to denote a positive degree of susceptibility of a variety to root- and basal stem-rot, but a light seed discoloration does not necessarily mean a relatively weak root infection. This is apparent from Table XLIX. It will be observed that there was practically no seed discoloration in 1924, yet severe root-rot developed on many varieties.

TABLE LII

CORRELATION BETWEEN DEGREE OF ROOT- AND BASAL STEM-ROT IN 102 VARIETIES OF WHEAT GROWN AT COON CREEK AND UNIVERSITY FARM IN 1923

Degree of root- and basal stem-rot, Coon Creek

Degree of root- and basal stem-rot, University Farm	5	6	7	8	9	10	11	12	13	
3				1						1
4	1	1								2
5	5	4	2	1	1		1			14
6	1	4	3	4	7	3				22
7	2	2	5	5	5	5	4	2		30
8		2		2	3	7	2			16
9		1	1		4	1	3	4		14
10				1	1					2
11									1	1
	9	13	12	14	21	16	10	6	1	102

$r = .5123 \pm .0493$

TABLE LIII

CORRELATION BETWEEN DEGREE OF ROOT- AND BASAL STEM-ROT OF 105 VARIETIES OF WHEAT GROWN AT COON CREEK AND UNIVERSITY FARM IN 1924

Degree of root- and basal stem-rot, University Farm	Degree of root- and basal stem-rot, Coon Creek							
	5	6	7	8	9	10	11	
4			1					1
5		2	1	1				4
6		8	10	1	1			20
7	1	7	14	7	3	1		33
8		2	8	3	1	1		15
9		1	6	2	3	1		13
10			2	2	5	1		10
11			1	1	3			5
12			2		1		1	4
	1	20	45	17	17	4	1	105

$r = +.4781 \pm .0512$

TABLE LIV

CORRELATION BETWEEN AVERAGE DEGREE OF ROOT- AND BASAL STEM-ROT OF 102 VARIETIES OF WHEAT GROWN AT COON CREEK AND UNIVERSITY FARM IN 1923 AND 1924

Average degree of infection in 1923	Average degree of infection in 1924							
	6	7	8	9	10	11	12	
5	2	2	1	1				6
6	3	9	4	1				17
7	3	7	5	3				18
8	4	10	8	1	3			26
9	1	7	3	1	9			21
10			5	3	1			9
11			2	1	1			4
12							1	1
	13	35	28	11	14	0	1	102

$r = .4367 \pm .0541$

TABLE LV

CORRELATION BETWEEN DEGREE OF SEED INFECTION IN 79 VARIETIES OF WHEAT GROWN AT UNIVERSITY FARM AND COON CREEK IN 1923

Degree of infection at University Farm	Degree of infection at Coon Creek										
	1	2	3	4	5	6	7	8	9	10	
1	10	5		1	1						17
2	7	4		1							12
3	5	1	8	3							17
4	5	1	1			1		1			9
5			2		1		3	1	2		9
6		1	1								2
7		1	1	1				2			5
8				1	1	1					3
9							1			1	2
10							1	1			2
11									1		1
	27	13	13	7	3	2	5	5	3	1	79

$r = +.6738 \pm .0414$

TABLE LVI

CORRELATION COEFFICIENT BETWEEN SEVERITY OF BASAL STEM- AND ROOT-ROT AND SEED INFECTION IN 102 VARIETIES OF WHEAT GROWN AT UNIVERSITY FARM IN 1923

Degree of root infection in 1923	Degree of seed infection in 1923											
	1	2	3	4	5	6	7	8	9	10	11	
3			1									1
4	1	1										2
5	8		5	1								14
6	7	5	3	3	1	2		1				22
7	12	3	7	1	3		1	1		1	1	30
8	3	2	3	3	2		1		1	1		16
9		11	1	1	4	1	3	2	1			14
10	1		1									2
11				1								1
	32	12	21	10	10	3	5	4	2	2	1	102

$r = +.4015 \pm .0560$

CONTROL MEASURES

The *Helminthosporium* disease of cereals is difficult to control. The pathogene lives over in and on the seed of several cereal crops and many wild and cultivated grasses. It develops saprophytically on plant remains in and on the surface of the soil and is an inter-crop parasite. The progress of the disease depends very largely on environmental conditions, but the pathogene is a virulent parasite under certain conditions.

Root-rot and basal stem-rot can not be controlled by planting clean seed in infested soil. However, the amount of seedling blight can be reduced by treating the seed with certain mercuric compounds, provided it is sown in comparatively clean soil. Such treatments also stimulate germination. They retard and partially eliminate primary infection and thus reduce the amount of inoculum early in the season, but they do not eliminate secondary infection and will not reduce the amount of blighting on foliage, spikes, and seed.

Rotation of crops is important in controlling root-rot and basal stem-rot. Observations indicate that the disease is more prevalent in fields which have been cropped continuously to wheat and barley than in those in which rotation has been practiced. As the organism overwinters in the soil, a rotation which includes immune or highly resistant crops such as corn, clover, timothy, or vegetables, is detrimental to the pathogene and consequently reduces the disease.

Early sowing of susceptible spring grains will aid somewhat in reducing the amount of seedling blight, because the optimum temperature for the cereal hosts is low while that for the pathogene is high. The time of sowing, however, does not affect the amount of spike, foliage, and seed blight. The destruction of susceptible grasses is important. The pathogene attacks at least 83 species of wild grasses belonging to 37 different genera (18). Many of these grasses are common weeds which produce a tremendous amount of inoculum.

Varietal resistence is of the utmost importance in controlling the disease, altho it must be remembered that resistance is only relative. The degree of infection is influenced profoundly by ecological conditions and cultural methods—rotation, etc. Velvet, Manchuria, and Svansota barleys (23) are resistant to *H. sativum*. The results of varietal tests with wheat indicate sufficient differences in susceptibility to make possible the selection and breeding of desirable resistant varieties.

DISCUSSION AND CONCLUSIONS

The disease of cereals caused by *Helminthosporium sativum* is prevalent and destructive in Minnesota every year; furthermore, it is widely distributed in the United States and other countries. Undoubtedly it causes great damage. The pathogene reduces the percentage of seed germination, causes seedling blight, kills older plants prematurely, infects the floral parts, and blights the seed, and often causes severe spotting of the foliage. In 1924, from 20 to 75 per cent of the plants of durum wheat in many fields in Minnesota were killed after they had headed. *H. sativum* was primarily responsible. On certain types of soil, especially peat, the disease is so destructive as to be a limiting factor in the production of wheat and barley.

H. sativum is a group species consisting of many physiologic forms. At least 37 can be recognized readily on culture media. The writer observed at least 50 distinct forms, and there are indications that there are numerous others. Eleven distinct forms were isolated from material collected in the vicinity of St. Paul alone. Most of the isolations from other regions were somewhat different.

Physiologic forms differ from each other strikingly on culture media in the following characters: habit of growth, rate of growth, amount of sporulation, zonation, color of mycelium, and temperature relations. The differences between forms sometimes are so great as to suggest the desirability of considering them as separate species.

The 37 forms on which an intensive study was made, differ from each other consistently even under identical conditions, and each form is very variable under different conditions. For this reason extreme caution is necessary in describing species, such as *H. sativum* and other fungi, which may vary equally much. Since a description of *H. sativum* based on the characters of all existing physiologic forms is quite impossible, the characters of at least a few of the forms should be taken into consideration.

Not only do the physiologic forms differ in general appearance on culture media, but they are strikingly different also in other respects. There is good preliminary evidence that different forms react quite differently to temperature. Most important of all, they differ pathogenically.

Many of the physiologic forms have quite different parasitic capabilities on wheat and barley. Some forms are extremely virulent, others are moderately virulent, and still others are only weak parasites. These differences in virulence of forms are of paramount importance, because they complicate the study of genetic inheritance and the development of resistant varieties. Varieties which are resistant in one region

may be very susceptible in another. Therefore a study of the number and parasitic capabilities of physiologic forms is prerequisite to sound procedure in breeding work. The problem is essentially local or, at best, regional. Results obtained in one locality may not be applicable in other localities. But this is not the worst feature of the situation. If one could be assured that these forms were relatively stable, the situation would not be especially bad. But they are not stable. Some of them are very unstable.

Mutations are extremely common on culture media. New forms are continually arising. Some forms mutate much more frequently than others. The mutants observed differed from the parents in rate of growth, color, zonation, amount of aerial mycelium, and pathogenicity. Relatively weak forms may produce very virulent mutants and vice versa. This change in parasitism is tremendously important. *H. sativum* is dynamic, not static. It is in a state of flux, and, consequently, presents a continually changing problem. There is every reason to suppose that mutation occurs in nature as well as on artificial media. A final solution of the problem is therefore extremely difficult.

The nuclear phenomena involved in the mutation of *H. sativum* are not known. The possibility of segregation as a result of nuclear fusion is not excluded, altho it does not seem to be very strong. Anastomosing hyphae have often been observed. Anastomosis between different types of *Helminthosporium* was noted by the writer. It is possible that hybridization may occur quite frequently. However, the mutants, which arise as sectors, suggest that the mechanism is somewhat analagous to bud mutations in higher plants.

The present studies have shown that the viability of the spores is greatly affected by ecological factors. The pathogene overwinters readily in the soil and in the seed. The organism is present in and on seed of resistant cereals. It also is a facultative saprophyte and grows on dead or dying plant remains. Primary infections may come from the seed or from the soil. High temperature and relatively high humidity are detrimental to the longevity of the spores, and lack of aeration results in their rapid death; but the conidia can withstand considerable alternation of temperature—thawing and freezing. They remain viable in the soil from one season to the next. It has been shown that the sowing of clean or treated seed does not insure plants free from infection if sown in infested soil.

The severity of disease is influenced profoundly by environmental conditions. The effect of moisture and temperature is twofold: the effect on the host and that on the pathogene. Factors such as soil fertility, physical characteristics, and chemical composition of the soil also influence the development of the disease. The maximum damage

from the disease results from conditions which are unfavorable for host development.

It is obvious that the control of *H. sativum* is difficult. The use of resistant varieties seems to be the most promising method of control. Resistant varieties of barley are known. Studies on varietal susceptibility of wheat to *H. sativum* indicate differences in resistance. Furthermore, the resistance is only relative. Extensive field experiments and observations for the last 5 years have shown that epidemics of *H. sativum* may occur in spite of the use of resistant varieties. It seems fair to conclude, therefore, that the use of resistant varieties must be in connection with clean seed, good cultural practice, and proper rotation of crops, in order to reduce the effects of the disease to a minimum.

SUMMARY

1. *Helminthosporium sativum* is widespread and destructive. It causes serious losses in Minnesota every year. It was isolated from material obtained in many states in the United States, from several places in Mexico and Canada, and from one place in Serbia.

2. *H. sativum* is a common inhabitant of cereal seeds. The amount present varies with the locality, year, and variety; but the percentage of infection is not actually correlated with the reaction of the plants in the field.

3. Over 1000 isolations were made from wheat plants affected with basal stem-rot. *H. sativum* was by far the most prevalent organism.

4. Zonation is fairly common but differs in the different forms. It apparently is caused by the amount and kind of medium and by alternating temperatures. Light is not essential, altho diurnal changes may induce zonation.

5. There are numerous physiologic forms of *H. sativum*. The writer studied 37 in detail. These forms can be distinguished in culture by the following characters: rate of growth; proportion of submerged and aerial mycelium; nature of mycelial growth, such as zonation, production of conidia, density of conidial clusters, and color of the mycelium.

6. The forms also differ from each other pathogenically. All forms can attack foliage, floral parts, and the roots of wheat and barley. Some forms are very virulent while others are relatively non-virulent. In general, there is a correlation between the virulence on wheat and barley.

7. The differences in the pathogenicity of different forms are so great that the conflicting results obtained by previous investigators can easily be explained.

8. Many physiologic forms may occur in the same region. On the other hand, the same physiologic form sometimes may occur in widely separated regions.

9. Asexual mutation occurs frequently in some forms of *H. sativum*. Mutants arise abundantly from some forms in artificial culture as wedge- or fan-shaped sectors. These mutants bred true when propagated from either spores or mycelium.

10. Mutations occur as frequently in monosporous cultures as in those produced from many spores or from mycelium.

11. Some forms mutate readily and others do not. Mutation was observed in forms from England, Australia, Africa, Argentina, Serbia, Canada, and many localities in the United States.

12. Reversions apparently occur and when they do they are always in the form of sectors.

13. The mutants differ from their parents not only in morphological characters, but also in pathogenicity. Some are more virulent than the parents while others are less so.

14. Many physiologic forms of *H. sativum* produce conidia abundantly on plant tissues and artificial media; others seldom fructify. All attempts to induce formation of perithecia were unsuccessful.

15. Light is not necessary for the formation of spores. The production of conidia of *H. sativum*, Form 1, was affected greatly by temperature. Different physiologic forms react differently to temperature. The optimum temperature for sporulation for Form 1 was between 16° and 25° C. The maximum was about 29° and the minimum about 10°.

16. The conidia of *H. sativum* remain viable for a long time under proper conditions. Those of several forms remained viable for 3 years, while a successful transfer was made from an old culture after it had been dormant and dry for almost 5 years.

17. The longevity of the spores depends somewhat on the physiological form concerned, altho environmental conditions have a greater effect.

18. Spores of Form 1 can withstand exposure to both low and high temperatures for considerable periods of time if the relative humidity is low. High temperatures and high relative humidity are deleterious. The spores can withstand long periods of alternate freezing and thawing. The conidia of Form 1 overwintered outside at University Farm, St. Paul. The percentage of spores which survive the winter differs in different seasons.

19. Aeration is important in determining the length of time conidia can remain viable.

20. Spore germination is influenced profoundly by slight changes in environment.

21. The addition of small bits of leaf tissue to distilled water stimulates spore germination and growth of germ tubes to a remarkable extent. Spores kept in a liter of water for a year failed to germinate, but when suspended in a small quantity of this water to which leaf tissue was added, 80 per cent germinated within 24 hours. The stimulatory agent is present in other plant tissues than those of susceptible hosts.

22. The virulence of Form 1 was not attenuated as a result of growing six years on artificial media.

23. The development of the *Helminthosporium* disease on cereals depends on several factors: The physiologic forms present; the amount of inoculum produced; the effect of environmental factors on the development of the pathogene; varietal susceptibility; and factors predisposing the host.

24. Heavy dews and rains together with high temperatures are conducive to foliage and spike infection.

25. The disease was most severe on peat soil with deep drainage. In 1924 practically all plants of Monad and Pentad wheat were killed by root-rots and basal stem-rots on four different water levels (2 to 5 feet), but not on the 1-foot water level.

26. Peat soils are likely to predispose plants to attack, because the plants are weaker than those growing on better soils.

27. Plants seem to be most susceptible to the disease from the milk stage on.

28. While temperature and moisture undoubtedly affect the development of the disease, it is evident that the virulence of the particular form concerned is often more important than certain environmental conditions.

29. Many dust and liquid fungicides were used in an attempt to find something that would kill the mycelium of *H. sativum* in the seeds of wheat and barley. None were entirely effective.

30. Treating the seed with fungicides did not affect the rate of growth of seedlings, nor did it control root-rot and basal stem-rot or increase the yields when the seed was sown in soil in which the organism was present. All varieties of *Triticum vulgare, T. compactum, T. durum, T. dicoccum, T. turgidum, T. spelta,* and *T. polonicum* became infected with root-rot and basal stem-rot. There were great differences in susceptibility, however. The durums, in general, were the most susceptible. There were sharp differences in the susceptibility of different varieties also among the common wheats.

31. There is a high correlation between the behavior of varieties to *H. sativum* when grown at different places in the same year and at the same places in different years. This indicates clearly that resistance of wheat is due to genetic factors the expression of which can, however, be influenced considerably by the environment and by the specialization of the fungus. Very unfavorable growing conditions may predispose even the most resistant varieties of wheat and barley, so that they may be severely attacked by virulent forms.

LITERATURE CITED

1. Aamodt, Olaf S. The inheritance of growth habit and resistance to stem rust in a cross between two varieties of common wheat. Jour. Agr. Res. 24:457-470. 1923.
2. Anderson, Paul J. The morphology and life history of the chestnut blight fungus. Bul. Comm. Invest. and Contr. Chestnut Tree Blight Dis. No. 7. 1914.
3. Atanasoff, D. Fusarium blight of the cereal crops. Mededeelingen van de Landbouwhoogeschool Deel 27. No. 4. 1923.
4. ———— and Johnson, A. G. Treatment of cereal seeds by dry heat. Jour. Agr. Res. 18:379-390. 1920.
5. Bisby, G. R. Zonation in cultures of *Fusarium discolor sulphureum*. Mycologia 17:89-95. 1925.
6. Blakeslee, Albert F. Sexuality in Mucors. Science n.s. 51:375-382, 403-409. 1920.
7. ————. Mutations in Mucors. Jour. Hered. 11:278-284. 1920.
8. Bolley, H. L. Wheat: soil trouble and seed deterioration. No. Dak. Agr. Exp. Sta. Bull. 107. 1913.
9. Bonar, L. Studies on the biology of *Brachysporium trifolii*. Am. Jour. Bot. 11:123-158. 1924.
10. Brierley, William B. On a form of *Botrytis cinerea*, with colourless sclerotia. Philos. Trans. Roy. Soc., London, Ser. B, 210:83-114. 1920.
11. ————. Discussion on mutation of species. Brit. Med. Jour. 2:722-726. 1922.
12. Brotherton, W., Jr. Further studies on the inheritance of "rogue" type in the garden peas (*Pisum sativum* L.). Jour. Agr. Res. 24:815-852. 1923.
13. Brown, William. Studies in the physiology of parasitism. VIII. On the exosmosis of nutrient substances from the host tissue into the infection drop. Ann. Bot. 36:101-119. 1922.
14. ————. Studies in the physiology of parasitism. IX. The effect on the germination of fungal spores of volatile substances arising from plant tissues. Ann. Bot. 36:285-300. 1922.
15. Buller, A. H. Reginald. Experiments on sex in mushrooms and toadstools. Nature 114:8. 1924.
16. Burger, O. F. Variations in *Colletotrichum gloeosporioides*. Jour. Agr. Res. 20:723-736. 1921.
17. Chaudhuri, H. A study of the growth in culture of *Verticillium albo-atrum*, B. et. Br. Ann. Bot. 37:519-539. 1923.
18. Christensen, J. J. Studies on the parasitism of *Helminthosporium sativum*. Minn. Agr. Exp. Sta. Tech. Bull. 11. 1922.

19. ———. Physiologic specialization and mutation in *Helminthosporium sativum*. Phytopath. 15:785-796. 1925.
20. ——— and Stakman, E. C. Foot- and root-rots of wheat in Minnesota in 1924. (Abs.) Phytopath. 15:53. 1925.
21. Crabill, C. H. Dimorphism in *Coniothyrium pirinum* Sheldon. Am. Jour. Bot. 2:449-467. 1915.
22. Dickson, James G. The influence of soil temperature and moisture on the development of seedling-blight of wheat and corn caused by *Gibberella saubinetii*. Jour. Agr. Res. 23:837-870. 1923.
23. Dodge, B. O. The life history of *Ascobolus magnificus*. Origin of the ascocarp from two strains. Myc. 12:115-134. 1920.
24. Dosdall, Louise T. Factors influencing the pathogenicity of *H. sativum*. Minn. Agr. Exp. Sta. Tech. Bull. 17. 1923.
25. ——— and Christensen, J. J. Variation in the length of spores of *Helminthosporium sativum* P. K. & B. under different conditions of growth. (Abs.). Phytopath. 13:50. 1923.
26. Drechsler, C. Some graminicolous species of *Helminthosporium*. Jour. Agr. Res. 24:641-740. 1923.
27. Eckerson, S. H. and Dickson, James G. The influence of soil temperature and moisture on the chemical composition of wheat and corn and their predisposition to seedling blight. (Abs.). Phytopath. 13:50-51. 1923.
28. Edgerton, C. W. Plus and minus strains in the genus *Glomerella*. Am. Jour. Bot. 1:244-254. 1914.
29. Ezekiel, Walter N. Strains of the brown rot fungus, *Sclerotinia americana*. (Abs.). Phytopath. 14:32. 1924.
30. Griffee, Fred. Correlated inheritance of botanical characters in barley, and manner of reaction to *Helminthosporium sativum*. Jour. Agr. Res. 30: 915-935. 1925.
31. Hamblin, C. O. "Foot-rot" of wheat caused by the fungus *Helminthosporium*. Agr. Gaz. New South Wales 33:13-19. 1922.
32. Hayes, H. K. and Stakman, E. C. Resistance of barley to *Helminthosporium sativum* P. K. & B. Phytopath. 11:405-411. 1921.
33. ———, Griffee, Fred, and Christensen, J. J. Reaction of barley varieties to *Helminthosporium sativum*. Part I. Varietal resistance. Part II. Inheritance studies in a cross between Lion and Manchuria. Minn. Agr. Exp. Sta. Tech. Bull. 21. 1923.
34. Headlee, Thomas J. Report Dept. Entomology, N. J. Agr. Exp. Sta., pp. 375-519. 1920.
35. Heald, F. D. and Smith, L. J. The dusting of wheat for bunt or stinking smut. Wash. Agr. Exp. Sta. Bull. 171. 1922.
36. Hedgcock, George Grant. Zonation in artificial cultures of *Cephalothecium* and other fungi. Rept. Mo. Bot. Gard. 17:115-117. 1906.
37. Henry, A. W. Root-rots of wheat. Minn. Agr. Exp. Sta. Tech Bull. 22. 1924.
38. Hoffer, G. N. A test of Indiana varieties of wheat seed for fungus infection. Proc. Ind. Acad. Sci. 1913:97-98. 1914.
39. Johnson, Thorvaldur. Studies on the pathogenicity and physiology of *Helminthosporium gramineum* Rab. Phytopath. 15:797-804. 1925.
40. Krakover, L. J. The leaf-spot disease of red clover caused by *Macrosporium sarcinaeforme* Cav. Proc. Mich. Acad. Sci. 19:275-328. 1917.
41. La Rue, Carl Downey. The results of selection within pure lines of *Pistalozzia guepini* Desm. Genetics 7:142-201. 1922.

42. Leach, J. G. The parasitism of *Colletotrichum lindemuthianum*. Minn. Agr. Exp. Sta. Tech. Bull. 14. 1923.
43. Levine, M. N. A statistical study of the comparative morphology of biologic forms of *Puccinia graminis*. Jour. Agr. Res. **24**:539-568. 1923.
44. Love, H. H. A modification of Student's table for use in interpreting experimental results. Jour. Am. Soc. Agron. **16**:68-73. 1924.
45. MacInnes, Jean and Fogelman, Raymond. Wheat scab in Minnesota. Minn. Agr. Exp. Sta. Tech. Bull. 18. 1923.
46. Mackie, William W. and Briggs, Fred N. Fungicidal dusts for the control of bunt. Calif. Agr. Exp. Sta. Tech. Bull. 18. 1923.
47. McKinney, H. H. Influence of soil temperature and moisture on infection of wheat seedlings by *Helminthosporium sativum*. Jour. Agr. Res. **26**: 195-218. 1923.
48. Matsumota, Takaski. Studies in the physiology of fungi. XII. Physiological specialization in *Rhizoctonia solani* Kuhn. Ann. Mo. Bot. Gard. **8**:1-62. 1921.
49. Mitra, M. *Helminthosporium spp.* on cereals and sugar cane in India. Part I. (Diseases of *Zea mays* and *Sorghum vulgare* caused by species of *Helminthosporium*). Mem. Dept. Agr. India **11**:219-242. 1923.
50. Müller, H. C. Die Bedeutung der ertragsteigernden Wirkung einiger Beizstoffe für die Volksernährung. Nachrichtenbl. deutsch. Pflanzenschutzdienst **3**:57-58. 1924. Rev. in Rev. Appl. Myc. **2**:550-551. 1923.
51. Noble, Robert J. Studies on the parasitism of *Urocystis tritici* Koern., the organism causing flag smut of wheat. Jour. Agr. Res. **27**:451-490. 1924.
52. Ocfemia, G. O. The *Helminthosporium* disease of rice occurring in the southern United States and in the Philippines. Am. Jour. Bot. **11**: 385-408. 1924.
53. Peltier, George L. A study of the environmental conditions influencing the development of stem rust in the absence of an alternate host: II. Infection studies with *Puccinia graminis tritici* Form III and Form IX. Neb. Agr. Exp. Sta. Res. Bull. 25. 1923.
54. Roberts, John W. Morphological characters of *Alternaria mali* Roberts. Jour. Agr. Res. **27**:699-708. 1924.
55. Stakman, E. C. and Lambert, E. B. Dusting seed grain to prevent smut. Minn. Agr. Ext. Spec. Bull. 70. 1923. (Out of print.)
56. ——— and Flor, H. H. Varietal resistance of spring wheats to *Tilletia levis*. Univ. of Minn. Studies in Biol. Sci. No. 5:307-316. 1924.
57. Stakman, E. C. and Levine, M. N. Effect of certain ecological factors on the morphology of the urediniospores of *Puccinia graminis*. Jour. Agr. Res. **16**:43-77. 1919.
58. ———, Parker, J. H. and Piemeisel, F. J. Can biologic forms of stem-rust on wheat change rapidly enough to interfere with breeding for rust resistance? Jour. Agr. Res. **14**:111-124. 1918.
59. ———, Piemeisel, F. J. and Levine, M. N. Plasticity of biologic forms of *Puccinia graminis*. Jour. Agr. Res. **15**:221-250. 1918.
60. Stakman, Louise J. A *Helminthosporium* disease of wheat and rye. Minn. Agr. Exp. Sta. Bull. 191. 1920.
61. ———. Some fungi causing root- and foot-rot of cereals. Univ. of Minn. Studies in Biol. Sci. No. 4:139-155. 1923.

62. Stevens, F. L. The *Helminthosporium* foot-rot of wheat, with observations on the morphology of *Helminthosporium* and on the occurrence of saltation in the genus. Ill. Dept. of Reg. and Educ. Div. Nat. Hist. Surv. Bull. 14:77-185. 1922.
63. ——— and Hall, J. G. Variation of fungi due to environment. Bot. Gaz. 48:1-30. 1909.
64. "Student." The probable error of the mean. Biometrica 6:1-25. 1908.
65. ———. Tables for estimating the probability that the mean of a unique sample of observations lies between $-\infty$ and any given distance of the mean of the population from which the sample is drawn. Biometrica 11:414-417. 1917.
66. Tisdale, W. H., Taylor, J. W. and Griffiths, Marion A. Experiments with hot water, formaldehyde, copper carbonate, and chlorophol for the control of barley smuts. Phytopath. 13:153-160. 1923.
67. Whitehead, T. On the life history and morphology of *Urocystis cepulae*. Brit. Mycol. Soc. Trans. 7:65-71. 1920.

PLATE I

Fig. 1. Cultures of *H. sativum* and *Alternaria spp.* Developed from Barley Seed on Potato Dextrose Agar

Fig. 2. Pure Cultures of *H. sativum* Developed from Basal Portions of Diseased Stem of Marquis Wheat

PLATE II

Fig. 1. Heads of Barley Inoculated in the Boot Stage with Three Physiologic Forms of *H. sativum*

A with Form 1
B with Form 5
C with Form 8
D control

Fig. 2. Heads of Wheat Inoculated in the Boot Stage with Three Forms of *H. sativum*

A Control
B Form 1
C Form 9
D Form 25

PLATE III

Ten-Day-Old Cultures of 18 Forms of *H. Sativum* Grown Under Identical Conditions on Oatmeal-Rice-Cornmeal Agar. Compare with Plate IV

PLATE IV

Ten-Day-Old Cultures of 18 Forms of *H. Sativum* Grown Under Identical Conditions on Potato Dextrose Agar. Compare with Plate III

PLATE V

Fig. 1. Seedling of Marquis Wheat Grown in Soil Inoculated at Time of Planting with *H. sativum,* Showing the Comparative Virulence of Different Forms of the Pathogene

A Control
B Form 26
C Form 21
D Form 3
E Form 19
F Form 22
G Form 8
H Form 5

Fig. 2. Seedlings of Mindum Wheat Grown in Soil Inoculated at Time of Planting with Forms of *H. sativum* Obtained from Widely Different Localities

A Control
B From Argentina
C From Serbia
D From Australia
E From Canada
F From Texas
G From England
H From Minnesota

PLATE VI

Seedlings Grown in Soil Inoculated with Approximately Equal Amounts of Inoculum of Different Fungi, Showing the Comparative Virulence of Each

A Control
B *Gibberella saubinettii*
C *Fusarium sp.*
D *Fusarium moniliforme*
E *H. sativum,* Form 8
F *H. sativum,* Form 1
G *H. sativum,* Form 21

PLATE VII

Fig. 1. *H. sativum,* Form 1, on Oatmeal-Rice-Cornmeal Agar, Showing Mutants

Fig. 2. *H. sativum,* Form 1, on Oatmeal-Rice-Cornmeal Agar, Slant Placed so that the Depth of Agar at the Bottom Was About Three Times That at the Top. Mutants Only on the Shallow Half of the Medium

PLATE VIII

Fig. 1. *H. sativum,* Form 31, Giving Rise to Similar Mutants

Fig. 2. *H. sativum,* Form 3, Producing Two Different Mutants, No. 51 (right) and No. 52 (left)

PLATE IX

Cultures Showing Homozygosity of *H. sativum,* Form 1, Obtained by Single-Spore Inoculations from a Monosporous Culture

Upper Row on Oatmeal-Rice-Cornmeal Agar; Lower Row, on Green Bean Agar

A Mass Transfer of Inoculum as Control
B-E Single-Spore Inoculations

PLATE X

Fig. 1. Seedlings of Marquis Wheat Grown in Soil Inoculated with *H. sativum,* Form 22 (back row), and Its Mutant, No. 40 (front row), Showing the Difference in Virulence of Parent and Mutant

Fig. 2. Seedlings of Trebi Barley Grown in Soil Inoculated with *H. sativum,* Form 22 (back row), and Its Mutant, No. 40 (front row), Showing Difference in Virulence of Parent and Mutant

PLATE XI

Mature Plants of Pentad Wheat Grown on Peat Soil at Two Different Drainage Levels, Showing Effect of Soil Moisture on the Development of Basal Stem-Rot

A One-Foot Drainage Level
B Three-Foot Drainage Level

PLATE XII

Colonies of *H. sativum* and *Alternaria spp.* Developing from Seed of Marlout Barley, Sown on Potato Dextrose Agar, After Treatment with Copper Carbonate (Fig. 1) and Silver Nitrate (Fig. 2).

H. sativum and *Alternaria spp.* Developed from all Seed Thus Treated

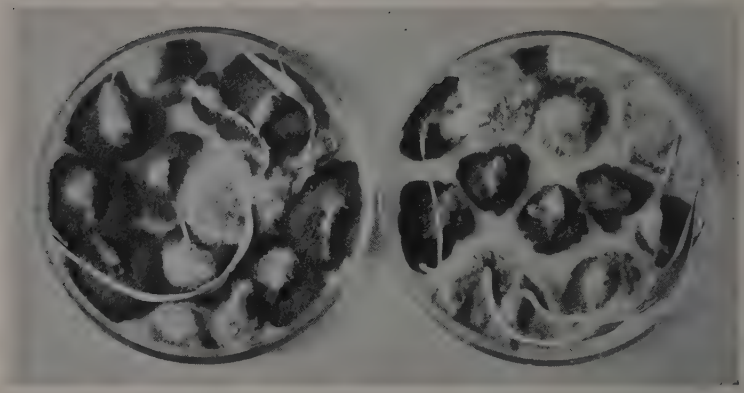


Figure 1

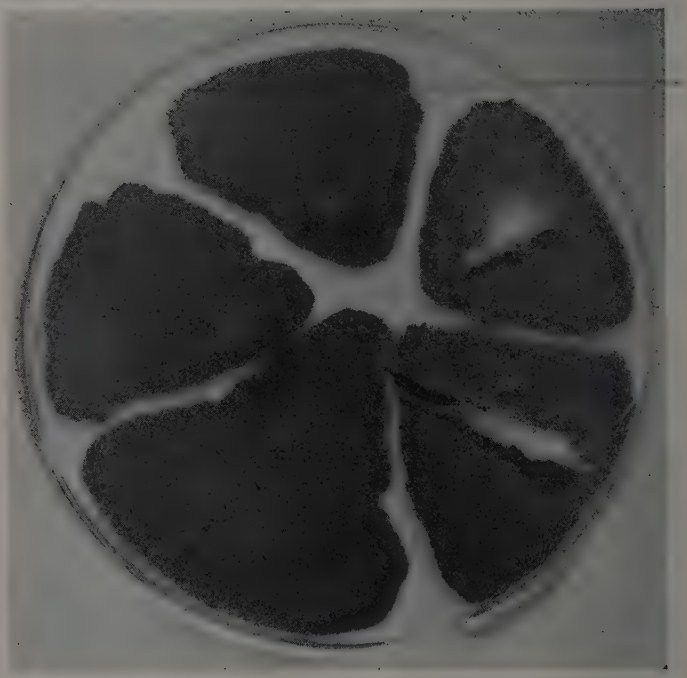


Figure 2



Figure 1



Figure 2

PLATE III

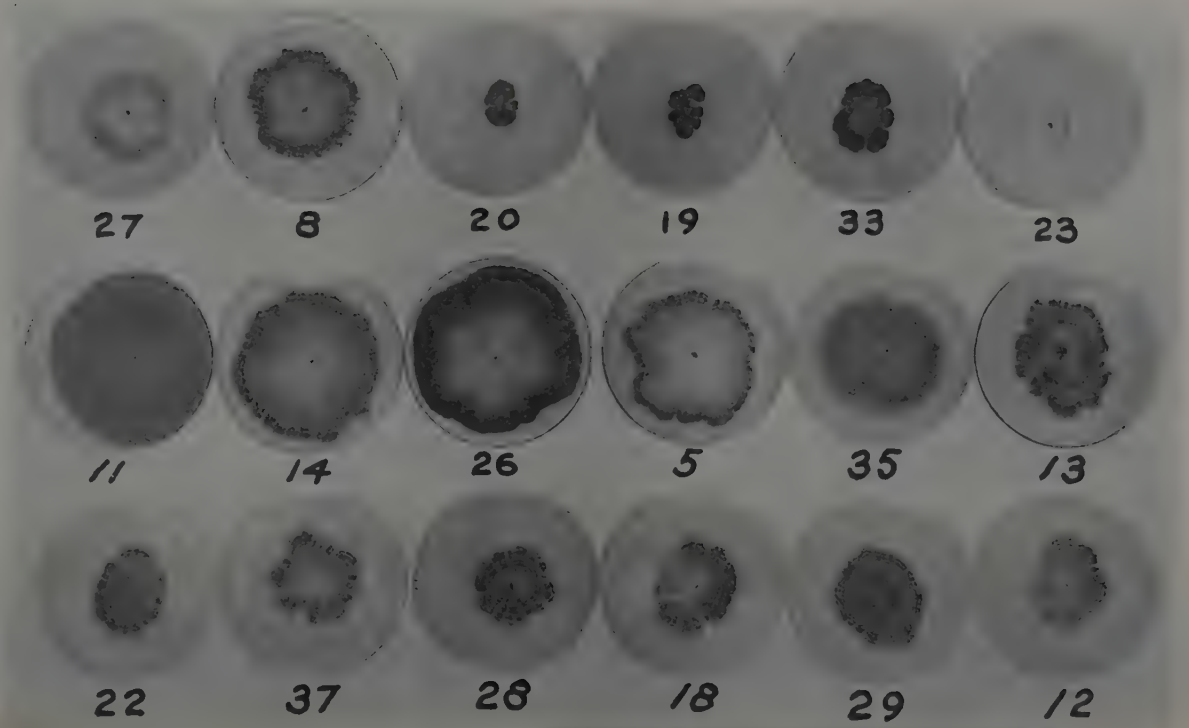


PLATE IV

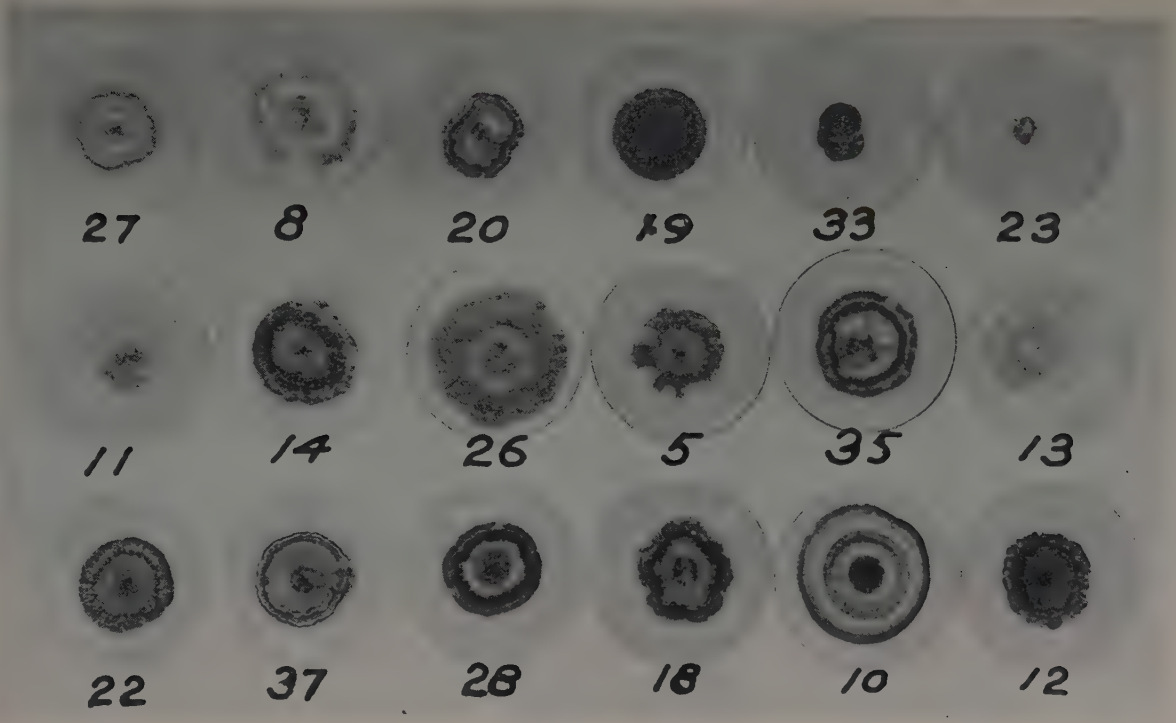


PLATE V



Figure 1

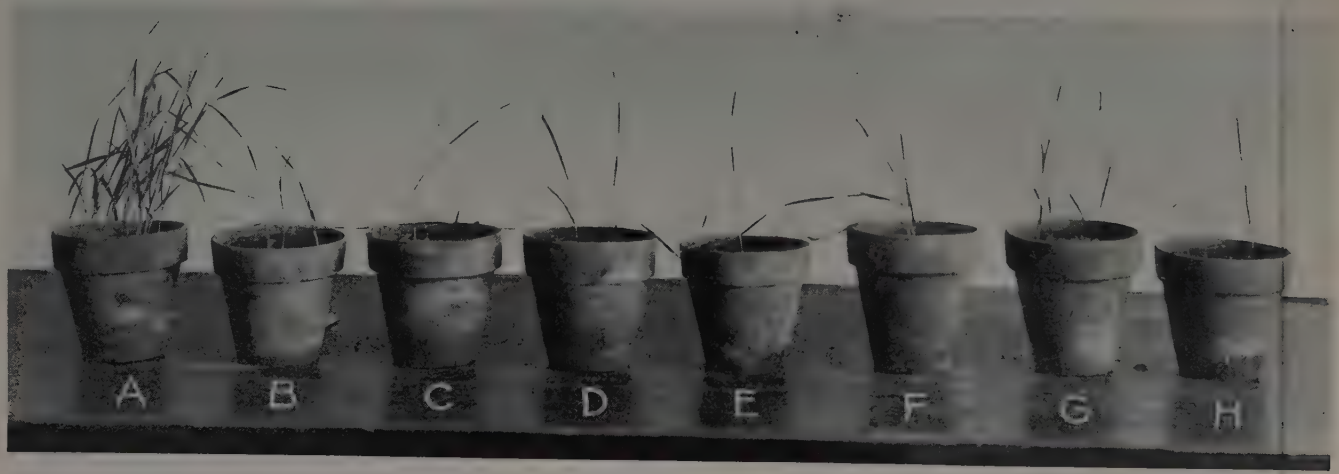


Figure 2

PLATE VI



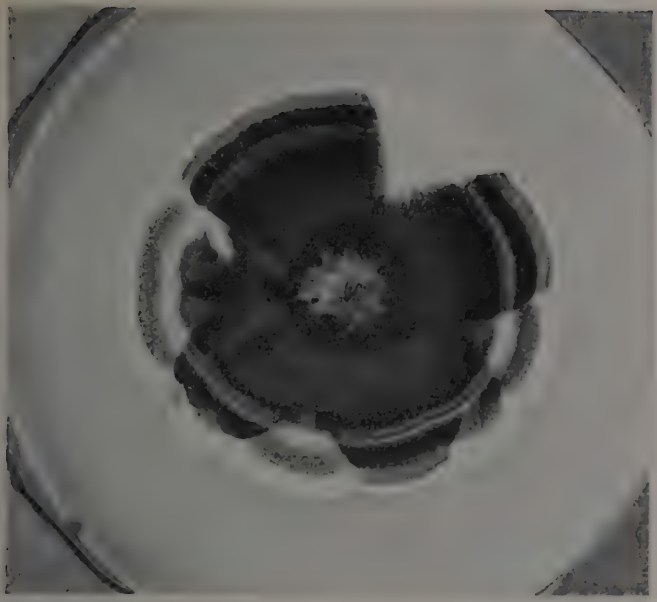


Figure 1

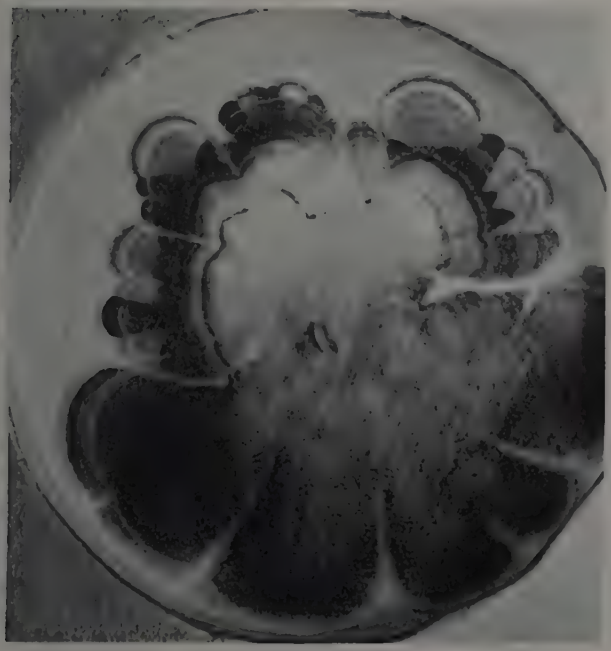


Figure 2

PLATE VIII

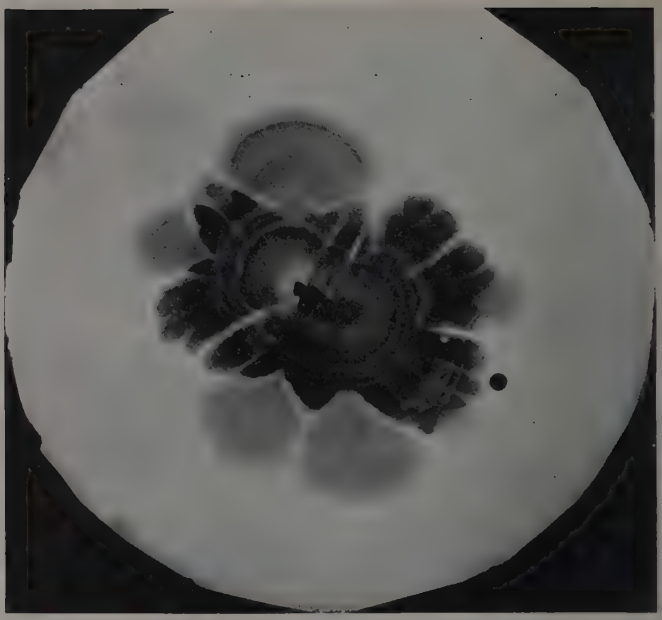


Figure 1

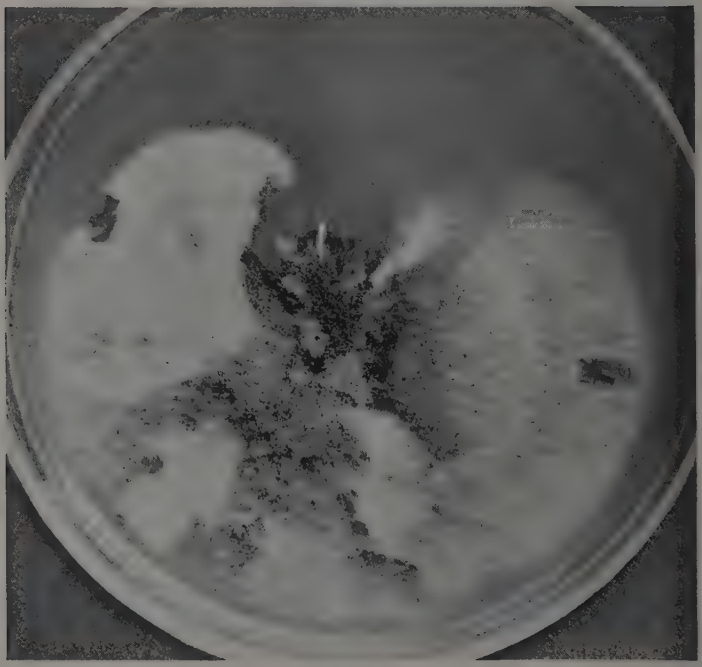


Figure 2

PLATE IX

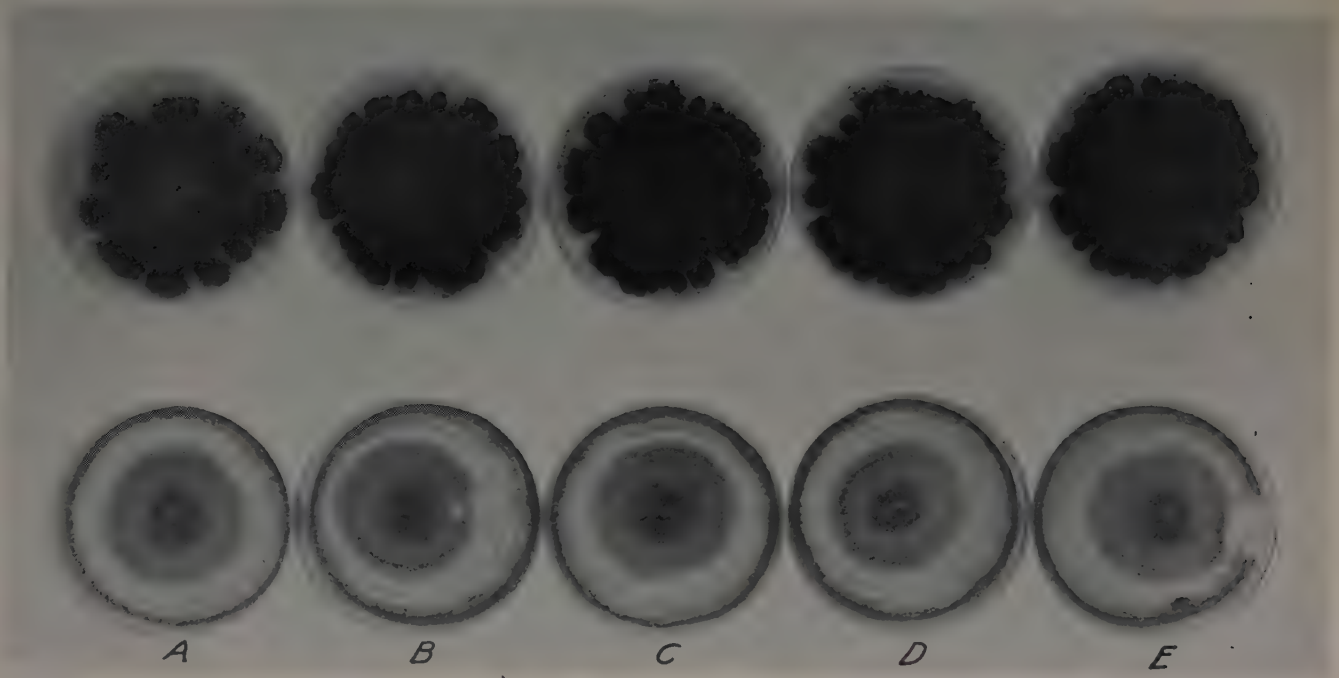




Figure 1

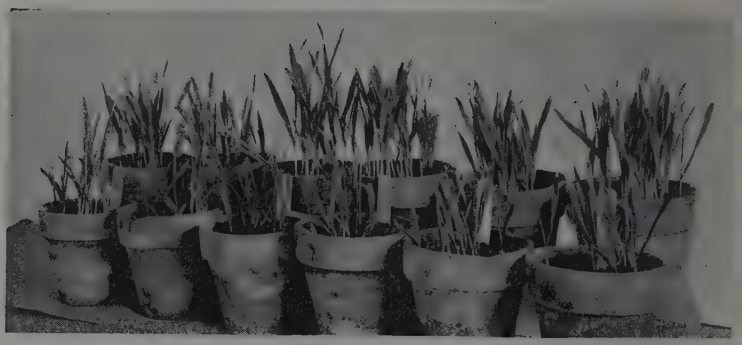
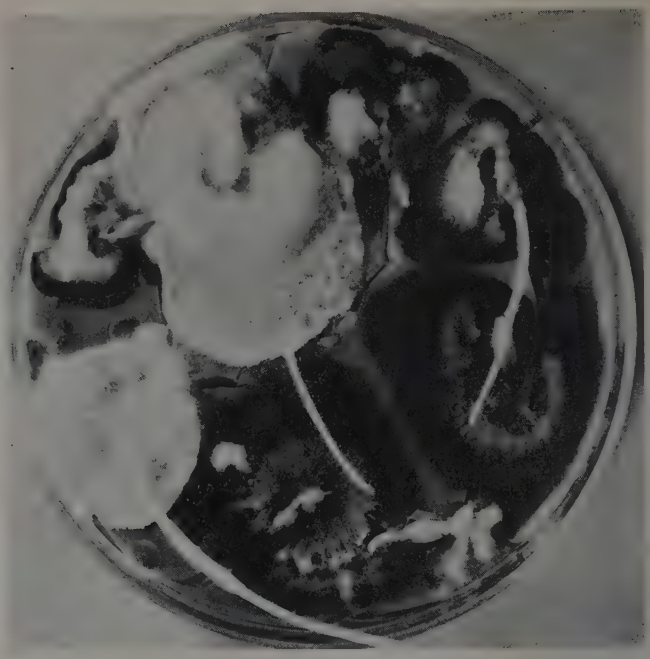


Figure 2

PLATE XI







TECHNICAL BULLETIN 38 JUNE 1926

University of Minnesota
Agricultural Experiment Station

Winter Hardiness in Alfalfa Varieties

Ferdinand H. Steinmetz
Division of Agronomy and Farm Management

UNIVERSITY FARM, ST. PAUL

The subject of this paper was suggested by Prof. Andrew Boss, while the details as to methods of procedure, helpful suggestions, and criticisms were given by Dr. R. B. Harvey. To these, thanks are due for providing ways and means for carrying out this work. To the section of plant physiology, Division of Plant Pathology and Botany, thanks are due for providing the major facilities needful for the completion of the work; to the Division of Biochemistry, for the use of apparatus; and to Dr. R. A. Gortner and Dr. J. J. Willaman for helpful suggestions. To Prof. A. C. Arny, who provided means and materials for the work, especially during the early investigational period; and to Mr. Esten Hendricks for his competent assistance in the carbohydrate and amino-nitrogen determinations, thanks are due.

WINTER HARDINESS IN ALFALFA VARIETIES[1]

By Ferdinand H. Steinmetz

INTRODUCTION

The importance of alfalfa as a forage crop is generally known. Likewise, the uncertainty of successful overwintering of the crop is known to be one of the greatest hazards of the alfalfa growers. This is particularly true in the northern part of the United States and in Canada, where the crop is of great importance to the livestock industry. Winter-hardy forms of alfalfa have been introduced from Europe, where they were found growing under climatic conditions similar to those in northern United States. Additional hardy forms have been produced by selection, while the production of hardy strains by hybridization is at present being carried on by several plant breeders. Types of root systems (50)[2] and the degree of dormancy (7) have been correlated with winter-hardy forms. However, in the final analysis, the isolation of winter-hardy strains has been dependent upon natural selection over several years. It is well known that so-called test winters occur occasionally—at intervals of ten or more years. Winter hardiness in winter wheat has been studied recently by Newton (32, 34), who used various methods and devices to measure the relative hardiness of wheat varieties. It was the purpose of this experimental work to employ available methods and apply them to two commonly recognized varieties of alfalfa—Grimm and Kansas grown common—with the hope that some light might be thrown on the basic differences between them.

WINTER KILLING OF SUBTERRANEAN PLANT PARTS

The work of previous investigators has been reviewed by Abbe (1), Blackman (5), Chandler (11), Rosa (38), Wiegand (48), and Newton (32). Since a large part of the literature of winter hardiness and winter killing is concerned principally with above-ground parts, a brief review only of the overwintering of subterranean parts and herbaceous plants will be given.

According to Goeppert (17), Theophrastus recommended covering the vine with soil and Cato recommended covering plants with straw to prevent winter killing. Goeppert (18) records temperature at Ustjanks, Siberia (70° 55″ N. Lat.), in which he gives the average temperature for the coldest month (January) to be —50° C. He also

[1] Also submitted to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the Degree of Doctor of Philosophy, June, 1926.

[2] Figures in parentheses refer to Literature Cited, page 31.

records the temperature at the surface of the soil under 4 inches of snow for the period February 4 to 16, inclusive. In addition, he determined the depth to which the soil was frozen and its temperature 2 inches below the surface. To illustrate, on February 5 at 6 a.m. the temperature of the atmosphere was —21.5° C. and at 7 a.m. the snow temperature at the surface of the soil was —6.2° C., while the soil temperature 2 inches below the surface for the same day was —1.2° C. He recognized that the roots of trees and herbaceous perennials were protected from low temperatures, while the tops of trees and certain forms of cryptogamic plant life endured the low temperature. Carrick (10) has reviewed the horticultural literature relative to root injury ascribable to low temperature. He also presents data on the differences in hardiness of the roots of certain horticultural stocks. Wahlen (46) investigated various native and cultivated herbaceous legumes grown at different altitudes in Switzerland, and found that they showed no autonomous winter rest period. He further found that practically no variation in root contraction existed. By the use of microchemical methods he determined the type of reserve materials present in the roots during the winter. In addition he measured the relative amount of carbohydrate reserve material in the roots by the use of the specific gravity method. He further compared the specific gravity of roots from plants which had not been cut during the summer with that from plants which had been cut twice during the growing season. In general the differences found were slight. While cutting stimulated the use of root reserves, it was observed that they were readily replaced during active growth.

Zacharowa (51) very recently determined the effect of low temperatures upon the root tissues of seedlings of rye, wheat, corn, peas, and buckwheat, which were grown in an incubator at 22.0° C. Preliminary experiments brought forth the commonly stated fact that young or meristematic tissues are more resistant to freezing than older tissues. She found that the root tips were more resistant than any other root tissue under observation. She further reports that the cortex and the root hairs are least resistant; the meristem is most resistant; and the central cylinder takes an intermediate place. In addition, cytological and microchemical studies revealed that the meristem was the richest in protein and that carbohydrates were practically absent. The less hardy tissues showed appreciable amounts of carboydrates as reducing sugars. Salts which Maximow (29) considered of importance as protective substances were not found in the root tip. The least resistant root was buckwheat. It was also the most acid in reaction. Further study showed that the least hardy tissues of a root were also the most acid. It was found that the highly resistant meristematic

region of the root tip was alkaline in reaction. As further experimental material in a study of the effect of alkali and acid upon tissue, red cabbage was used. It was found that acid hastened the killing of the tissue, while alkali retarded it. As a result this author refutes the theory that sugars and salts are protective, but defends the theory of acid precipitation of cell proteins as a cause of death from freezing. Further evidence of the resistance of young tissue is found in Winkler's report (49). He points out in an extended list of plants that the young leaf-bud tissue is the most frost resistant part of young shoots.

Sylvén (44) reports an experiment in which hardy and non-hardy varieties of alfalfa were tested at Svalöf. He found Grimm to be one of the most hardy varieties. Another phase of his article deals with the time of cutting in autumn in relation to overwintering. He does not emphasize root reserves, but does differentiate between early and late fall cutting. He believes that early fall cutting forces the inactive buds into growth but does not provide enough time for new buds to reach a stage of development capable of overwintering. He observed that very late cutting (after hard frosts) did not result in increased winter injury.

Unpublished data by G. Nilsson-Leissner[3] showed that by the refrigeration method he was able to differentiate between the hardy and non-hardy strains of alfalfa. In addition, he reports that reducing sugars and total nitrogen determinations did not show significant varietal differences.

MATERIALS AND METHODS

The experimental material consisted of roots of two physiologically different varieties of alfalfa. Grimm, a strain hardy under Minnesota conditions, has been described by Brand (6, 8), while Kansas grown common is a non-hardy form which has been grown for many years under conditions prevailing in the state of Kansas. All material used for physical and chemical data was grown in field plots under normal conditions. The seed was sown in May, 1922, without a nurse crop; and the experimental period, for the principal part, included the two winters between the fall of 1922 and the summer of 1924. Seedling plants which were used in studying dormancy and the killing points under controlled conditions, were grown in 6-inch flower pots embedded in the field. The roots for the expression of the cell sap, dry weight determinations, and chemical samples were dug from similar areas of contiguous plots. The tops were removed below the crown and the roots washed in tap water. Later the surface water was removed with

[3] Communication from Mr. Nilsson-Leissner, of Svalöf.

a towel, and an electric fan was used to remove all apparent surface moisture. During the winter, large lumps of frozen soil which separated at the plow sole approximately 7 inches deep were broken out with pickaxes. The frozen lumps were allowed to thaw over night in a warm room, after which the roots were removed as previously stated. Part of the soil was usually still frozen at the time the roots were removed.

The clean roots were then cut into pieces half an inch to an inch in length. After thoro mixing, duplicate samples for dry weight determinations were taken, and dried in an oven to constant weight. In addition, duplicate 50-gram samples for chemical analysis were dropped into fruit jars containing boiling alcohol and 1 gram of pure calcium carbonate. Enough 95 per cent alcohol was added to leave the final alcoholic concentration at 80 per cent [Spoehr (43), Davis, Daish, and Sawyer (13)]. The sample jars were then tightly sealed and stored. The remaining portion was put into a small cloth bag and frozen by the use of liquid CO_2 until the pieces were hard. This material was then ground with a food chopper, placed in closed containers, and kept in a cold place or put on ice. The freshly ground material was expressed in a large press operated by a hand screw which allowed the application of heavy pressure, or in a hydraulic press under a maximum pressure of 400 kilograms per square centimeter. The sap was then centrifuged for 10 minutes at a speed of approximately 2000 r.p.m., using an axis with a radius of 8 inches. A homogeneous liquid was thus prepared. The total solids were determined directly by the use of a standardized refractometer with a sugar scale attached, as was done by Gortner and Hoffman (21). The freezing point depression was determined with the Beckmann apparatus or a Heidenhain cryoscope with a range of —7.5° C.

The depression of the freezing point of the root tissue was determined by the thermo-electric method, first proposed by D'Arsonval (4) and later improved by Dixon and Atkins (14); and used by several European and American investigators (2, 23, 37). White (47) has shown its accuracy. The arrangement of apparatus illustrated by Harvey (24) was used. By this method duplicates on the same root frequently varied from 0.3 to 0.5° C. Miss Payne (36) used this type of apparatus in studying the freezing point of various insect larvae. The actual freezing point depressions reported here represent the average of from six to twenty readings taken on from two to ten roots. The roots used were brought in from the field and kept on ice until determined. In no case were they out of the soil more than four hours. By this method the undercooling rarely was greater than —2.0° C., and usually less than —1.5° C. Corrections were made for

undercooling by the use of the formula given by Harris and Gortner (22). Since the completion of this experimental work, an investigation by Zacharowa (51) has been called to the writer's attention. She used the thermo-electric method to determine the freezing points of seedling roots of rye, wheat, corn, peas, and buckwheat. In order to protect the tender roots from desiccation she suspended them in small vials.

RESULTS—PHYSICAL DETERMINATIONS

DORMANCY AND REST PERIOD

Throughout the following discussion the term "rest period" will be considered as an autonomous condition in a plant during which it shows no growth activities and from which it will not spring into active growth when provided with favorable conditions; while "dormancy" is an apparently inactive condition forced upon plants by external conditions unfavorable to growth. In this paper the dormancy of alfalfa is considered as being brought on by low temperatures prevailing during winter.

Wahlen (47) found that *Medicago sativa* L., *Trifolium pratense* L., *Onobrychis viciaefolia* Scop. and *Anthyllis vulneraria* L. had no rest period. To obtain information on the relative dormancy of the two varieties under study, frozen lumps containing the roots were brought in from the field on January 16, 1923, and again on January 9, 1924, and placed in the greenhouse. Definite unfolding of young leaves was apparent in both varieties after 3 days. Potted plants were brought in each month throughout the two winters and used as checks on freezing experiments. Some measurements of the new growths were made, but the data do not indicate any difference in the rate of growth of the two varieties. Fluctuations in the rate of growth occurred in both varieties. These fluctuations apparently give an indication of the vigor of the individual plants. All observations under controlled conditions and in the field during early spring showed no measurable difference in the dormancy of the two varieties.

CRITICAL PERIOD

The alfalfa plants frozen in the soil which were brought in during January for the two years, gave no marked evidence of killing during the winter. Roots dug for freezing point determination and for sap expression were uninjured throughout the two winters. Dead plants first appeared at the time of the spring thaw in 1923 and 1924. One sample for chemical determinations was taken February 7, 1925. At this time no dead plants were observed. During the thawing period,

March 18 to 27, thermo-electric readings were taken daily. On March 21 the first dead roots were observed and the number increased daily until March 27. At this time there were more dead roots in the Kansas common than there were living ones. An occasional dead root appeared in the Grimm variety at the latter date. One might expect to find a similar critical period during the fall if unfavorable changes of temperature should occur suddenly. However, during the interval under observation no such condition obtained. For comparison of the effect of this winter on other crops, it may be mentioned that observations (3) made in January, 1923, with several varieties of red clover, showed that the tender southern European sorts were entirely killed at that date, while the more hardy northern European sorts were uninjured.



Plate I. Potted Plants of Grimm and Kansas Alfalfa Exposed at the Same Temperature During the Winter

Note the killed and weakened plants of the tender variety while the hardy variety shows practically no injury.

KILLING POINT OF ALALFA PLANTS

During the first year the laboratory equipment for obtaining low temperatures consisted of a Dewar beaker containing petroleum ether into which a copper coil was fitted. The material to be frozen was placed in a tightly stoppered bottle and submerged in the ether bath. The temperature was regulated by admitting liquid carbon dioxide into the coil. By this method temperatures of —40.0° C. were obtainable and could be held practically constant. By the use of this device it was found that fresh roots brought in from the field showed distinct differences in the killing point of the two varieties (Plate I). On April 6, 1923, the Grimm plants frozen at 10.0° C. were either killed

or injured while the Kansas plants were all killed. At —5.0° C. the Grimm plants were uninjured while the Kansas plants were either killed or injured. During the winter of 1924-25 a large refrigerator was available in which electrically controlled temperatures lower than —30.0° C. were obtainable. Seedling plants sown in late July were grown in 6-inch flower pots for use in determining the killing point while in the soil mass. The results of freezing potted plants are given in Table I.

TABLE I

EFFECT OF LOW TEMPERATURES UPON ALFALFA PLANTS COLLECTED AT DIFFERENT TIMES AND DIFFERENCE IN KILLING POINT BETWEEN THE TWO VARIETIES

Variety	Date	Minimum temperature	Time*	Results
		°C.	Hours	
Grimm	10/ 8/24	—11.9	12	Killed
Kansas	10/ 8/24	—11.9	12	Killed
Grimm	10/ 9/24	— 4.5	12	Uninjured
Kansas	10/ 9/24	— 4.5	12	Uninjured
Grimm	10/10/24	—13.5	12	Killed
Kansas	10/10/24	—13.5	12	Killed
Grimm	10/24/24	— 9.6	12	Injured
Kansas	10/24/24	— 9.6	12	Killed
Grimm	10/25/24	—12.5	12	Injured
Kansas	10/25/24	—12.5	12	Killed
Grimm	12/26/24	—11.0	12	Injured
Kansas	12/26/24	—11.0	12	Badly injured and killed
Grimm	2/ 3/25	Checks	..	Uninjured
Kansas	2/ 3/25	Checks	..	Uninjured
Grimm	2/ 3/25	—22.0	12	Slight injury
Kansas	2/ 3/25	—22.0	12	Killed to badly injured
Grimm	2/ 5/25	—17.0	12	Uninjured
Kansas	2/ 5/25	—17.0	12	Killed
Grimm	2/ 6/25	— 8.0	12	Uninjured
Kansas	2/ 6/25	— 8.0	12	Uninjured
Grimm	2/10/25	—28.5	12	Killed
Kansas	2/10/25	—28.5	12	Killed
Grimm	3/13/25	— 8.0	12	Uninjured
Kansas	3/13/25	— 8.0	12	Injured
Grimm	3/13/25	Checks	..	Uninjured
Kansas	3/13/25	Checks	..	Uninjured
Grimm	3/16/25	—14.0	12	Injured
Kansas	3/16/25	—14.0	12	Badly injured to killed
Grimm	3/18/25	— 5.0	12	Uninjured to slightly injured
Kansas	3/18/25	— 5.0	12	Badly injured to killed
Grimm	7/20/25	— 6.0	12	Killed
Kansas	7/20/25	— 6.0	12	Killed
Grimm	7/21/25	— 3.0	12	Killed
Kansas	7/21/25	— 3.0	12	Killed

* Trials showed that injury had reached its maximum and was not increased up to 24 hours.

It will be observed that there is a seasonal progression of cold resistance during the fall and early winter and a regression during the spring. For example, on October 8 both varieties were killed at —11.9° C., while on October 25 Grimm plants survived —12.5° C. but Kansas plants did not. It seems that the maximum cold resistance

for both varieties during February, 1925, was near —22.0° C. This resistance was lost during the early part of March, which was the time of the spring thaw. It is of interest to note that in the summer condition both varieties killed at —3.0° C. By comparing the data further, it will be seen that the Grimm variety endures lower temperatures than the Kansas variety under hardened conditions.

The data in Table II, supplied by the section of farm crops, were taken from thermograph records for the winter 1923-24.

TABLE II

TEMPERATURES AT SURFACE OF SOIL AND AT ONE INCH BELOW SURFACE

Date	Air temperature at surface, minimum	Soil temperature 1 inch below surface, minimum	Surface covering
	°C.	°C.	
12/21/23	—7.2	—2.2	Snow
1/23/24	—3.9	—3.3	"
2/ 4/24	—1.1	—1.7	"
3/13/24	—4.4	—2.8	"
3/24/24	0.0	—2.2	"
4/ 2/24	0.0	—1.7	"
4/21/24	+3.3	+1.7	No snow

From the data presented it is obvious that snow protects the plants from low temperatures as well as from sudden fluctuations. Goeppert (17) recorded similar observation in 1830. He also observed that roots of hardy plants killed at —12.5 to —18.7° C.

From the winter-killing point of alfalfa plants, as indicated in Table I, it is apparent that a covering of snow provides certain protection to these plants against winter killing. As previously shown, the resistance to low temperature is appreciably decreased during March thaws. In addition, it has been found by thermograph records at University Farm that when the surface is bare the daily minimum soil temperature near the surface is approximately as low as that of the atmosphere.

Roots killed by low temperature are readily detected, as they appear watery when cut in cross-section. When the sections are squeezed between the fingers, sap readily exudes at the cut surface, while living roots show no exudation under similar treatment. Dead roots readily disintegrate when thawed out, so that soon after the spring thaw they become moldy and decay. Evidence of the relative frost resistance of the crown tissue and root tissue is of interest at this point. Under field conditions as well as under controlled greenhouse conditions, it was frequently observed that the crown buds began to unfold but soon died back. This was caused by dead root tissue. Examination of weakened plants revealed that the central region of the root was browned and later decayed, leaving a hollow root (Plate II). Chandler

(11) found that the pith cells of young twigs of apple killed first as the result of severe cold. Root injury was observed under field and controlled greenhouse conditions. Goeppert, and more recently Apelt and others, observed that repeated freezing finally killed plant tissue. This, however, may be due to disturbed metabolism under experimental conditions rather than to low temperatures. It may well be questioned whether repeated freezing and thawing occurs under natural conditions in the soil.



Plate II. Effect of Winter Killing on Kansas Common Alfalfa
(Photo May 5, 1923)
Left, Injured; Right, Uninjured.

FREEZING POINT DEPRESSION OF ROOT TISSUE—THERMO-ELECTRIC METHOD

In freezing all samples, the bath was held as near —10.0° C. as possible. Sections of alfalfa root approximately one-fourth inch long were used. A hole, made into the tissue with a pin, permitted the firm insertion of the thermo-couple. All samples were allowed to undercool —1.5 to —2.0° C. Within this temperature range, inoculation was induced by jarring the apparatus. The advantage of considerable undercooling lies in the resulting rebound which facilitates obtaining a freezing point that is maintained for about a minute. The Leeds and Northrup Type K potentiometer was used for determining the potentials. A summary of the data is presented in Table III and Chart I, Figure A. A study of the results shows that in general no absolute correlation exists between the degree of the freezing point depression of the tissue and resistance to killing by freezing. For example, on December 29, 1922, the freezing point depression of the tissue for the Kansas variety was —3.2° C. while on July 5, 1923, the depression was —3.3° C. for the same variety. It is known from data previously presented that the actual killing points would be approximately —15.0° C. for the winter sample while it is known to be at —3.0° C. and undoubtedly higher, for the summer sample. This is in accord with the data presented by Rein (37), who found that no relation existed between cell turgor and its killing point. Harvey and Regeimbal (25), working with several species of trees and shrubs, found that in July the killing point was practically coincident with the freezing point. During the autumn the killing point gradually dropped until in November it had reached —27.0° C. while the freezing point remained fairly constant.

It will also be observed that the freezing point depression of the tissue is not so great during the winter months as in late autumn and early spring. In general, the seasonal trend of the freezing point depression of the tissue for the two varieties is similar, altho certain fluctuations occur. Close examination shows that for the critical period each spring Grimm had a somewhat greater depression. This difference was lost after the ground had thawed and growth had begun. While this difference is not great, it was found to prevail during each of the three years in which the study was carried out.

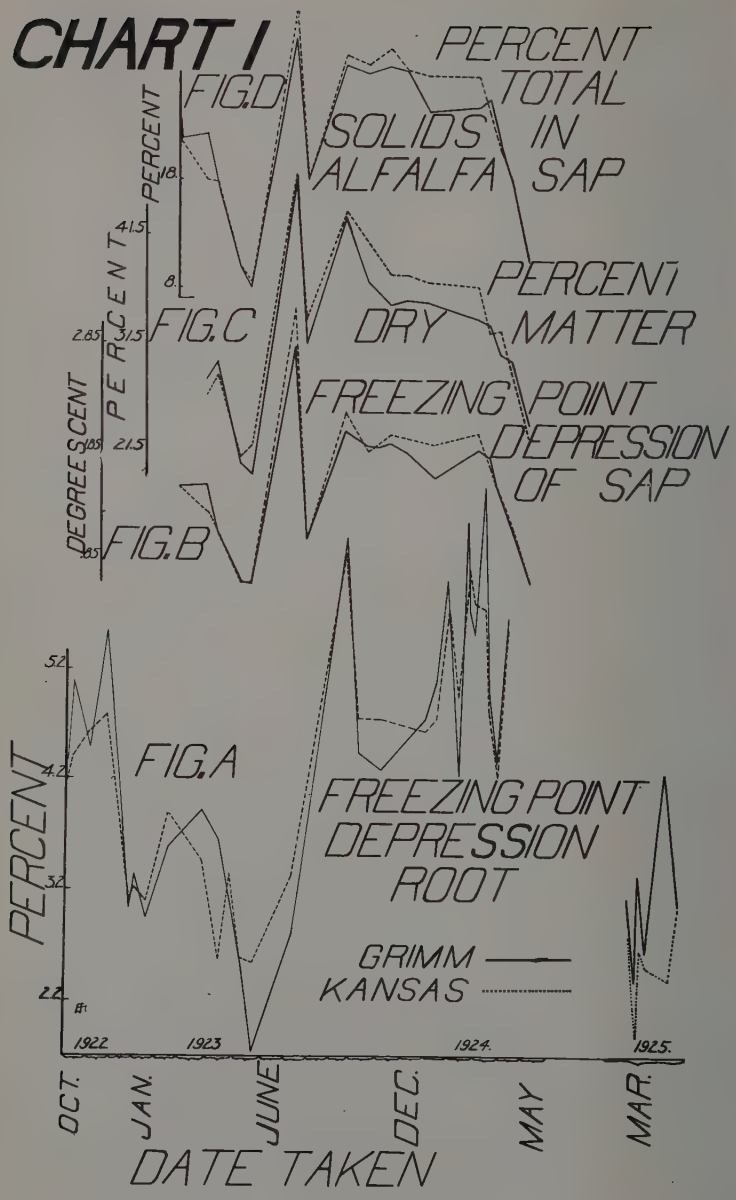
TABLE III

INFLUENCE OF ENVIRONMENT UPON FREEZING POINT DEPRESSION OF ROOT TISSUE OF ALFALFA AS DETERMINED BY THE THERMO-ELECTRIC METHOD

Date	Kansas		Grimm	
	Δ	Osmotic pressure atmospheres	Δ	Osmotic pressure atmospheres
10/10/22	4.172	49.93	4.469	53.49
10/16/22	4.422	52.89	5.099	60.96
11/ 3/22	4.643	55.51	4.477	53.61
11/26/22	4.783	57.17	5.553	66.29
12/22/22	3.099	37.30	3.036	36.47
12/29/22	3.212	38.50	3.340	40.05
1/16/23	3.098	37.30	2.943	35.27
2/17/23	3.899	46.71	3.571	42.79
3/26/23	3.461	41.48	3.920	46.95
4/14/23	2.566	30.86	3.658	43.88
4/23/23	3.336	39.93	3.093	37.06
5/ 5/23	2.573	30.86	2.522	30.26
5/19/23	2.534	30.38	1.741	20.92
7/ 5/23	3.321	39.81	2.793	33.48
10/ 1/23	6.266	74.73	6.358	75.81
10/18/23	4.753	56.81	4.437	53.13
11/ 8/23	4.741	56.69	4.275	51.23
1/ 9/24	4.639	55.51	4.737	56.69
1/26/24	4.754	56.81	5.082	60.72
2/ 2/24	5.592	66.76	5.978	71.37
2/ 4/24	5.758	68.77	5.936	70.90
2/16/24	4.940	59.06	4.226	50.64
2/25/24	5.658	67.47	6.542	78.09
2/28/24	6.143	73.29	5.736	68.53
3/ 8/24	5.798	69.12	5.518	65.93
3/22/24	5.748	68.65	6.869	81.63
3/25/24	4.822	57.64	4.998	59.78
4/ 1/24	4.212	50.40	4.345	52.06
4/17/24	5.553	66.29	5.651	67.47
3/18/25	2.754	33.00	3.099	37.18
3/19/25	1.859	22.24	2.351	28.23
3/20/25	2.628	31.57	3.311	39.69
3/21/25	2.473	29.66	2.613	31.33
3/25/25	2.354	28.23	4.229	50.64
3/27/25	3.020	36.23	3.017	36.23

FREEZING POINT DEPRESSION OF SAP

The readings for freezing point depression were made on expressed and centrifuged sap. Previous investigators (15, 20) have shown that the freezing point depression of press juice prepared from unfrozen tissue was less than that of press juice prepared from tissue which had been frozen previously. As the maximum freezing point depression of a sap was obtained from prefrozen material, and as relative checks were thus obtainable, it was assumed that such sap represented the cell contents. Harvey (23) presents data on the freezing point depression of cabbage juice obtained by prefreezing the tissue and by expressing without prefreezing. He concludes that juices expressed from frozen tissues do not represent the true concentration of the cell sap for all of its constituents. Newton, Brown, and Martin (35)



Physical Data of Root Tissue and Expressed Sap

report the results of a study concerning the methods of extracting a plant press juice and its utility in physiological studies. They say: "Undoubtedly pre-freezing of the tissues is desirable when only the osmotic pressure and conductivity of the fluids are to be determined, though clearly it does not obviate the necessity of standardizing the procedure followed in pressing out. When, however, the object is to obtain the cell contents in a condition as nearly as possible unchanged, pre-freezing is impracticable. Specifically, its precipitating effect on proteins necessitates its omission when the juice is to be used for the study of colloidal properties or protein distribution." Data are presented in their paper which show that previous treatment of the tissue markedly affects the freezing point depression of the sap. After discussing the factors involved which may influence the freezing point depression of the sap, the writers make the following statement: "The experimental results given in Table III can not therefore be held to either prove or disprove the assumption that the press-juice has the same composition as the original tissue fluids." Data presented by Harvey and also by Newton seem to point definitely to the conclusion that a press juice obtained by prefreezing the tissues does not represent the true concentration of the cell sap for all of its constituents.

As a precision method, the Heidenhain cryoscope used on plant saps was more accurate in determining the freezing point of a given sample of sap than was the thermo-electric method in determining the freezing point of a section of a root of alfalfa. However, the question still to be answered is: What is a press juice in terms of the true cell contents? A Heidenhain cryoscope with a temperature range of $-7.5°$ C. was found to facilitate freezing point determinations. These data, shown below, do not correlate with the relative winter hardiness of the varieties nor with the winter hardened condition of the plants. Evidently the freezing point depression can not be used as a measure of winter hardiness. An examination of Table IV and Chart 1, Figures B and D, shows that the freezing point depression of the sap is closely correlated with the total solids, as shown by the refractometer readings. The greatest depression was obtained on July 26, when the plants were wilted because of drouth and the moisture content of the root tissue was low. The smallest depressions were obtained during the active growing period, when the moisture content was high and the total solids in the sap were low. This condition prevailed during May for the two years under study. It should be borne in mind that all root material used in this experiment was undoubtedly killed, as the temperature of solid carbon dioxide is $-79.0°$ C. under the conditions used, while the lowest killing point

of alfalfa roots investigated in the hardened condition was approximately —28.0° C. Newton (34) found a hardy variety of wheat the leaves of which apparently endured —40.0° C. in a hardened condition while the leaves of tender varieties were killed. Undoubtedly the sap obtained both from living and from killed leaf tissue accounted for some of the differences which he obtained.

TABLE IV

INFLUENCE OF ENVIRONMENT UPON FREEZING POINT DEPRESSION AND TOTAL SOLIDS IN PREPARED PRESS JUICE

Date	Kansas			Grimm		
	Freezing point depression	Total solids at 20° C.	Osmotic pressure atmospheres	Freezing point depression	Total solids at 20° C.	Osmotic pressure atmospheres
	°C.	Per cent		°C.	Per cent	
10/18/22	2.160*		25.95	2.148*		25.83
3/ 3/23	1.526	21.41	18.40	1.523	21.75	18.28
4/ 6/23	1.292	17.80	15.52	1.542	22.20	18.52
4/20/23	1.119	17.75	13.48	1.102	17.25	13.24
5/ 5/23	0.636	10.00	7.71	0.648	9.96	7.83
5/19/23	0.649	8.50	7.83	0.634	8.00	7.59
7/26/23	3.156	33.50	37.91	2.784	30.80	33.36
8/ 7/23	1.041	17.90	12.52	1.038	18.10	12.52
10/ 2/23	2.192	29.25	26.31	2.023	28.43	24.28
10/27/23	1.831	29.90	22.00	1.887	28.30	22.72
11/12/23	1.900	28.50	22.84	1.876	27.70	22.60
11/27/23	1.986	22.80	23.92	1.905	25.20	22.96
12/21/23	1.960	28.00	23.56	1.823	27.80	21.88
1/19/24	1.908	27.50	22.96	1.599	24.20	19.24
3/13/24	1.978	27.40	23.80	1.856	24.60	22.36
3/24/24	1.701	24.10	20.44	1.789	25.30	21.52
4/ 2/24	1.525	20.55	18.40	1.547	20.82	18.64
4/21/24	1.138	17.90	13.72	1.116	17.70	13.48
5/17/24	0.653	10.42	7.83	0.645	10.57	7.83
2/ 7/25	1.457	20.04	17.56	1.432	19.66	17.20

* Leaf sap.

TOTAL SOLIDS IN SAP

These determinations were made under uniform conditions at 20° C. and are recorded in Table IV and Chart 1, Figure D. No relation exists between the winterhardiness of these two varieties and the percentage of total solids. The highest reading of total solids was obtained July 26, 1923, when the soil was dry enough to cause the plants to wilt. There appears to be a positive correlation between the available moisture in soils and the percentage of total solids in the sap. This is in line with the general theory of hydrophyllic colloids.

VISCOSITY OF SAP

These determinations were made with a viscosimeter of the Ostwald type, in which the sap flowed through a capillary at a constant temperature of 20.0°C. The data in Table V represent the time in seconds required for 1.5 cc. of sap to flow through the capillary. By referring to the data on total solids for the same samples, it will be

seen that a positive correlation exists between the percentage of total solids and viscosity, but no consistent differences exist for the two varieties under study.

TABLE V

INFLUENCE OF ENVIRONMENT UPON PERCENTAGE OF DRY WEIGHT IN ROOTS, PERCENTAGE OF TOTAL SOLIDS IN EXPRESSED JUICE, AND VISCOSITY OF EXPRESSED JUICE AT 20° C.

Variety	Date	Dry weight in sample	Total solids in sap	Viscoscity (water = 126 sec.)
		Per cent	Per cent	Seconds
Grimm	3/ 1/23		23.65	
Kansas	3/ 1/23		22.80	
Grimm	3/ 3/23		21.75	
Kansas	3/ 3/23		21.41	
Grimm	4/ 6/23	28.13	22.20	
Kansas	4/ 6/23	26.62	17.80	
Grimm	4/20/23	29.72	17.25	601
Kansas	4/20/23	28.50	17.75	523
Grimm	5/ 5/23	20.31	9.96	255
Kansas	5/ 5/23	20.80	10.00	220
Grimm	5/19/23	19.26	8.00	279
Kansas	5/19/23	21.79	8.50	301
Grimm	7/26/23	45.99	30.80	1114
Kansas	7/26/23	46.70	33.50	1305
Grimm	8/ 7/23	31.34	18.10	748
Kansas	8/ 7/23	33.55	17.90	464
Grimm	10/ 2/23	42.95	28.43	775
Kansas	10/ 2/23	43.63	29.25	792
Grimm	11/12/23	36.99	27.70	
Kansas	11/12/23	40.77	28.50	
Grimm	11/27/23	34.77	28.30	
Kansas	11/27/23	37.62	29.90	
Grimm	12/21/23	35.25	27.80	676
Kansas	12/21/23	37.63	28.00	823
Grimm	1/19/24	35.04	24.20	
Kansas	1/19/24	36.93	27.50	
Grimm	3/13/24	33.55	24.60	
Kansas	3/13/24	36.50	27.40	
Grimm	3/24/24	33.17	25.30	
Kansas	3/24/24	32.34	24.10	
Grimm	4/ 4/24	30.32	20.82	
Kansas	4/ 4/24	32.59	20.55	
Grimm	4/21/24	29.72	17.70	
Kansas	4/21/24	28.50	17.90	
Grimm	5/17/24	23.82	10.57	
Kansas	5/17/24	22.67	10.42	
Grimm	2/ 7/25	32.26	19.66	
Kansas	2/ 7/25	32.97	20.04	

BOUND WATER AS A MEASURE OF WINTER RESISTANCE

The press juice was obtained from roots which were prepared according to the method previously described. The centrifuged sap was kept on ice and determinations were completed within eight hours. Newton and Gortner (33) present a method of estimating the hydrophyllic colloid content of expressed plant tissue fluids. In brief, the

procedure is as follows: The freezing point depression of a freshly prepared plant press juice is determined. Then the total solids are determined by the refractometer, using the method proposed by Gortner and Hoffman (21). Using the total solids as a basis, just enough press juice is weighed out to contain 10 grams of water, to which exactly 3.422 grams of pulverized sucrose is added. After this is dissolved, the freezing point depression is determined and is usually found to have increased more than the theoretical 2.085° C., allowing for the formation of sucrose hexahydrate. It is assumed that the excess is a measure of the bound water held by cell colloids and therefore not available for the solution of sugar. The application of this method to a limited number of samples showed no correlation between the bound water of the varieties in a hardened condition and winter hardiness, nor did it give a strikingly higher percentage of bound water for the samples taken during winter and early spring, as shown in Table VI. The symbols used as headings for columns 4, 5, 6, and 7 are the same as those used by Newton and Gortner (33).

TABLE VI

Influence of Environment upon Percentage of Total Solids, Freezing Point Depression, and Bound Water in Plant Press Juice of Two Varieties of Alfalfa

Variety	Date	Total solids	Δ*	Δa	$\Delta a - \Delta$	$\Delta a - (\Delta + Km)$	Bound water
		Per cent					Per cent
Grimm	11/12/23	27.7	1.876	4.370	2.494	0.409	14.6
Kansas	11/12/23	28.5	1.900	4.383	2.483	0.398	14.3
Grimm	11/27/23	25.2	1.913	4.289	2.376	0.291	10.9
Kansas	11/27/23	22.8	1.982	4.509	2.527	0.442	15.6
Grimm	1/19/24	24.2	1.554	3.901	2.347	0.262	9.9
Kansas	1/19/24	27.5	1.911	4.366	2.455	0.370	13.3
Grimm	3/13/24	24.6	1.859	4.310	2.451	0.366	13.3
Kansas	3/13/24	27.4	1.987	4.544	2.566	0.481	16.5
Grimm	3/24/24	25.3	1.702	4.120	2.418	0.333	12.4
Kansas	3/24/24	24.1	1.792	4.183	2.391	0.306	11.4
Grimm	4/ 4/24	20.8	1.540	3.931	2.391	0.306	11.4
Kansas	4/ 4/24	20.6	1.492	3.983	2.491	0.406	14.5
Grimm	4/21/24	17.7	1.077	3.364	2.287	0.202	7.9
Kansas	4/21/24	17.9	1.083	3.371	2.287	0.202	7.9
Grimm	5/17/24	10.6	0.641	2.941	2.300	0.215	8.4
Kansas	5/17/24	10.4	0.658	2.982	2.324	0.239	9.2

*Δ Freezing point depression of freshly expressed juice.

Δa Freezing point depression after the addition of the sugar.

$\Delta a - \Delta$ Actual added depression due to added sugar.

$\Delta a(\Delta + Km)$ This is equal to $(\Delta a - \Delta) - 2.085$, the amount by which the depression found on the addition of sugar is in excess of that expected on theoretical grounds.

The percentage of bound water is calculated by the formula, Bound water $= \frac{\Delta a\,(\Delta + Km)\,89.2}{\Delta a - \Delta}$, where 89.2 is the percentage of free water in a free molar solution of sucrose. Scatchard (39) has studied the hydration of sucrose in the light of previous investigations. He found strong evidence of the presence of a hexahydrate. While

vapor pressure measurements apparently did not agree with the presence of either a hexahydrate or a heptahydrate alone, he concluded that in view of all possible errors a hexahydrate met the conditions best.

Newton found a close correlation between bound water and winter hardiness of wheat varieties. He further measured the hydrophyllic colloid content of Cereus and Bryophyllum which were grown in the greenhouse. The results indicate a high hydrophyllic colloid content for Cereus and a total absence of such colloids in Bryophyllum. He also found that gum arabic, when added to water, acts as a hydrophyllic colloid in direct proportion to the amount added. Data presented in Table VI give evidence of the presence of hydrophyllic colloids in alfalfa roots. As previously stated, this measurement does not differentiate the hardy from the non-hardy variety.

VOLUME OF PRESS JUICE

The volume of press juice was taken according to the procedure of Newton. The data presented in Table VII show no relation to known hardiness of the material. As a measure of difference in imbibitional force which has been used by Newton in wheat, this method has no significance in relation to the material at hand.

TABLE VII

VOLUME OF PLANT PRESS JUICE PER 100 GRAMS OF FROZEN TISSUE OBTAINED AT VARIOUS PRESSURES IN RELATION TO THE TIME OF SAMPLING

Variety	Date	Kilograms per square centimeter pressure				
		50	100	200	300	400
		cc.	cc.	cc.	cc.	cc.
Grimm	11/12/23	8.2	9.0	9.4	11.2	11.4
Kansas	11/12/23	3.9	4.2	4.5	4.7	4.9
Grimm	11/26/23	16.2	18.8	21.0	21.0	21.0
Kansas	11/26/23	17.3	22.2	22.4	22.4	22.4
Grimm	11/27/23	11.7	15.2	16.1	16.2	16.2
Kansas	11/27/23	6.1	7.3	8.0	8.0	8.0
Grimm	12/21/23	7.5	8.9	10.4	11.0	11.5
Kansas	12/21/23	6.4	7.5	8.2	8.4	8.4
Grimm	1/19/24	13.5	21.6	26.3	27.5	28.3
Kansas	1/19/24	10.4	12.0	13.0	14.1	14.3
Grimm	3/13/24	15.2	19.7	25.8	27.7	28.0
Kansas	3/13/24	8.7	12.5	14.5	15.6	16.1
Grimm	3/24/24	10.8	14.0	17.0	18.2	18.9
Kansas	3/24/24	11.5	14.8	16.2	17.3	17.6
Grimm	4/ 2/24	20.0	22.5	25.0	26.0	26.5
Kansas	4/ 2/24	20.5	24.3	32.4	34.5	35.6
Grimm	4/21/24	14.8	18.4	20.5	21.5	22.1
Kansas	4/21/24	14.8	17.0	19.3	20.0	20.0
Grimm	5/17/24	17.8	20.9	24.0	25.1	26.3
Kansas	5/17/24	33.0	42.0	45.3	47.3	49.3
Grimm	2/ 7/25	21.0	27.4	31.5	33.2	34.0
Kansas	2/ 7/25	26.7	31.3	35.4	36.3	37.3

CHEMICAL DETERMINATIONS

PREPARATION OF SAMPLES FOR ANALYSIS

Dry weight determinations were made on duplicate samples of approximately 10 grams of fresh material which were dried to constant weight in an electrically heated oven at 100.0° C. The total organic nitrogen determinations were made by the Kjeldahl-Gunning method, using the residues from the dry weight samples.

Extraction of sugars and soluble nitrogen.—The preserved alcoholic samples were extracted on a steam bath in large Landsiedl extractors until the Molish test became negative. The volume and concentration of alcohol were approximately maintained by the occasional addition of small quantities of 95 per cent alcohol. Extraction was usually complete within from 18 to 24 hours. The extract was removed from the bath and the diluted alcoholic portion was made up to 500 cc. volume in water. After transferring to a large separatory funnel, 20 cc. of chloroform was added. This was thoroly shaken and set aside overnight. The chloroform containing the lipoid material was then drawn off. Following this a 10-cc. portion of chloroform was added and later drawn off. The chloroform extract containing the lipoid material was dried on a steam bath and weighed. No quantitative significance is given to this fraction.

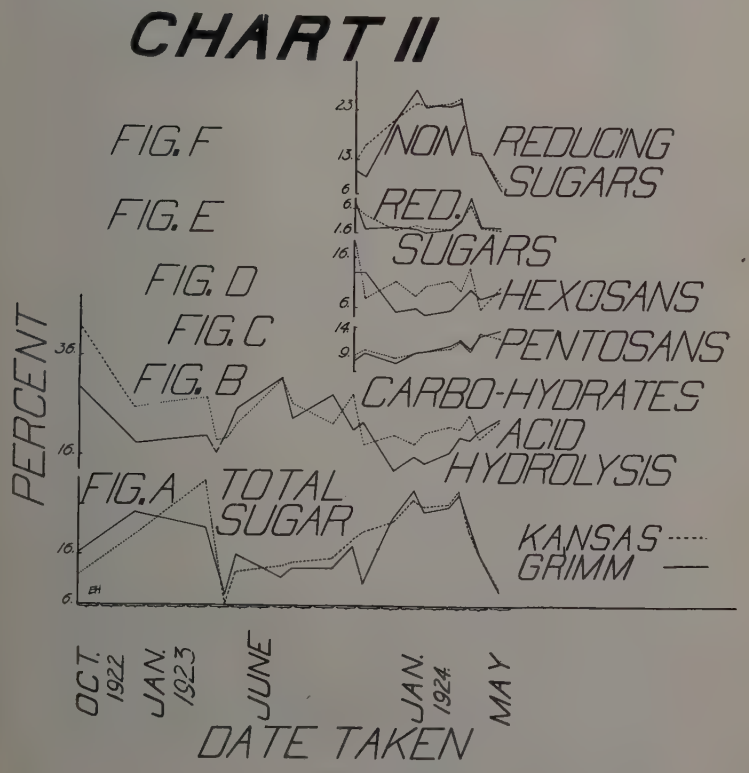
The extract was concentrated in the Claissen (45) apparatus under a reduced pressure of 20 to 25 mm. with the distillation flask in a water bath at a temperature from 40.0° to 60.0° C. Each sample was previously divided into two equal 250-cc. aliquots. The first aliquot, used for nitrogen determinations, was evaporated to a thick viscous mass in order to assure the removal of all alcohol. Later it was transferred and made up to a 100-cc. volume in hydrochloric acid (1:5) for nitrogen determinations. The other aliquot, which was used for sugar determinations, was reduced to approximately 25 cc. It was then taken up in approximately 170 cc. volume with distilled water and transferred to a 250-cc. volumetric flask previous to clarification,

Clearing extract for sugar analysis.—According to the method proposed by Horne (27), powdered neutral lead acetate was added in small quantities until no additional precipitate was formed. The solution was then allowed to stand until coagulation was completed. After this di-sodium phosphate was added in small quantities to precipitate the excess lead. Before filtering, sufficient water was added to bring the volume up to 250 cc. The clear filtrate was then ready for sugar determination.

DETERMINATIONS AND RESULTS

Soluble carbohydrates.—Soluble carbohydrates were extracted by alcohol and determined as total sugar and reducing sugar.

Total sugar.—Of the clarified filtrate, 75 cc. was placed in a 100-cc. volumetric flask to which 5 cc. of concentrated hydrochloric acid was added. This was then set away to wait for inversion at room temperature for 24 hours. Thereupon the contents were nearly neutralized with strong sodium hydroxide. It was found that this point could be readily observed by color change of the diluted extract. Neutralization was then completed with pure sodium carbonate. Following this, the volume was made up to 100 cc. and the reducing sugars were determined in triplicate 10-cc. portions. The copper determinations were carried out according to the thiosulphate titration method as given in the Official Methods of Analysis of the Association of Official Agricultural Chemists. The data in Table VIII and Chart II, Figure A, give the results based upon the material and method used in estimating total sugars.



Carbohydrate Data Calculated in Per Cent of Dry Weight

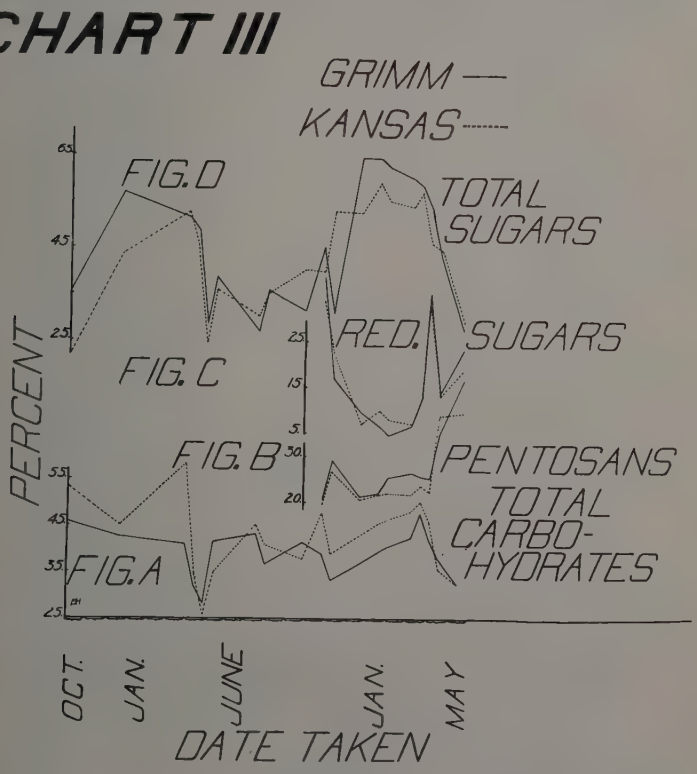
TABLE VIII

EFFECT OF THE ENVIRONMENT UPON THE CARBOHYDRATES IN ALFALFA ROOTS CALCULATED ON THE DRY WEIGHT BASIS

Date	Kansas						Grimm					
	Total carbohydrates in residue. Acid hydrol.	Total sugars	Reducing sugars	Non-reducing sugar	Pentosans	Hexosans	Total carbohydrates in residue. Acid hydrol.	Total sugars	Reducing sugars	Non-reducing sugar	Pentosans	Hexosans
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
10/19/22	41.45	11.91					29.49	16.47				
12/26/22	25.20	19.81					18.27	24.34				
4/ 6/23	27.40	30.97					19.63	21.35				
4/23/23	18.87	15.81					16.37	15.70				
5/ 5/23	19.25	6.31					20.23	8.11				
5/19/23	22.30	12.69					25.24	16.18				
7/26/23	31.42	13.75			7.98	23.44	31.41	11.67			8.88	22.53
8/ 7/23	26.31	14.47					23.45	13.26				
10/ 2/23	22.51	15.33					28.15	13.23				
10/30/23	28.47	19.19	6.59	12.60	9.36	19.11	21.27	17.76	6.98	10.78	8.19	13.08
11/10/23	18.06	20.74	4.71	16.03	10.38	7.68	22.87	10.36	1.80	8.56	9.71	13.16
12/21/23	20.14	22.88	1.61	24.49	8.91	11.23	13.06	23.59	2.31	21.28	7.86	5.20
1/23/24	18.29	27.10	2.71	24.39	9.89	8.40	15.79	29.03	1.95	27.08	9.88	5.91
2/ 4/24	20.54	25.89	2.12	23.77	10.26	10.28	14.59	24.64	1.16	23.48	10.03	4.56
3/13/24	21.96	26.36	1.86	24.50	10.55	11.41	16.68	25.74	1.80	23.94	11.23	5.45
3/24/24	21.39	29.10	3.45	25.65	12.02	9.37	19.73	28.04	3.45	24.59	12.30	7.43
4/2/24	24.44	21.01	6.87	14.14	10.27	14.17	19.21	22.64	8.04	14.60	10.60	8.60
4/21/24	19.44	16.02	2.13	13.89	13.79	5.65	21.10	16.55	2.24	14.31	13.24	7.86
5/17/24	23.01	9.45	1.68	7.77	12.79	10.22	23.40	8.91	2.09	6.82	14.31	9.09
2/ 7/25	19.98	24.03	3.63	20.40	9.74	10.24	18.07	23.77	3.47	20.30	11.44	6.63

Reducing sugar.—Reducing sugars were determined directly on 25-cc. portions of the clarified and filtered extract. The same technic was used as is given under total sugars. The data are reported in Table VIII and in Chart II, Figure E.

Insoluble carbohydrates in residue.—This represents all carbohydrate material left in the residue after the extraction in hot alcohol. Two separations were made: (1) that fraction which is hydrolyzed by direct acid hydrolysis, as outlined in A. O. A. C. official methods, which includes besides starch the pentosans and other carbohydrates; (2) that fraction which is determined as pentosans according to official methods. For convenience these will be referred to as total insoluble carbohydrates and pentosans. The total insoluble carbohydrates were determined in duplicate on a 2-gram sample of the residue remaining after alcoholic extraction. The samples were brought to constant weight and hydrolyzed. The hydrolyzed samples were treated as previously indicated for total sugars. Pentosans were determined in duplicate on 1-gram samples and finally calculated from the phloro-



Carbohydrates

Fig. A, per cent of total carbohydrates in alfalfa roots. Figs. B, C, and D, expressed in percentages of total carbohydrates.

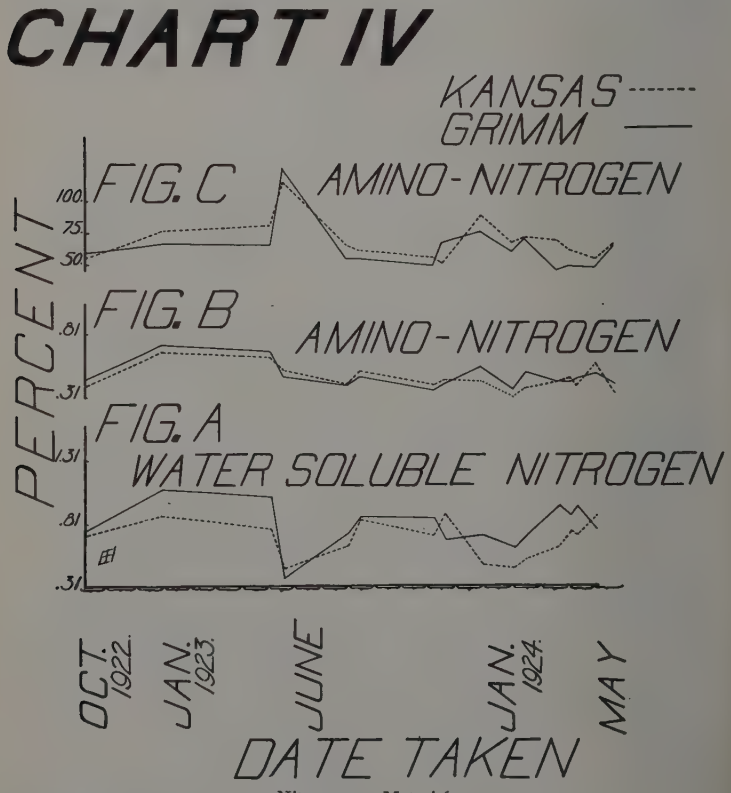
glucide precipitate, allowing for the proper solubility factor as given in A. O. A. C. official methods.

The results are found in Table VIII and Chart II, Figures B and C. Total carbohydrates other than pentosans have been determined by difference and indicated as hexosans. The greater part of this may be considered starch.

Nitrogenous material.—This is divided into three fractions, namely, the total organic nitrogen in the dry weight residue, the total alcohol-soluble organic nitrogen, and the amino-nitrogen extracted in alcohol.

The total organic nitrogen in the dry weight residues is available only in part, owing to the loss of the residues in storage.

The total alcohol-soluble organic nitrogen was determined on 25-cc. portions of the concentrated extract prepared as for amino nitrogen. The results are presented in Table X and Chart IV, Figure A. The difficulties encountered in determining nitrate nitrogen in solutions have been thoroly discussed by Bristol and Page (9). While it is assumed



Nitrogenous Material

Figs. A and B are percentages on dry weight basis. Fig. C is amino-nitrogen expressed in per cent of total water-soluble nitrogen.

that nitrate nitrogen may occur in alfalfa root material, no determinations have been made.

Amino nitrogen was determined by use of the Van Slyke apparatus (45), using 10-cc. portions of the filtered extract. Preliminary trials gave an appreciably higher yield when deaminization was continued one hour rather than the usual 6 minutes. Thus the data reported are based upon the amount of nitrogen liberated in one hour. The data are presented in Table X and Chart IV, Figure B.

DISCUSSION

CARBOHYDRATE RESERVES IN RELATION TO OVERWINTERING OF ALFALFA

From the data shown in Table VIII it is obvious that large quantities of carbohydrate reserves are stored in the roots of alfalfa plants. These reserves are drawn upon largely during the period of early spring growth. Nelson (31) has pointed out that low carbohydrate root reserves are one cause of winter killing in alfalfa. More specifically, he emphasizes the danger of cutting so late in autumn that there would not be sufficient leaf surface or time before freezing weather for the plant to accumulate ample reserves. However, he does not indicate quantitatively what relative amounts of reserves are necessary for overwintering. Wahlen (46) found that the root reserves were not entirely used in early spring, which is in accord with data presented in this report.

Fisher (16) was the first to make an extensive study of the carbohydrate reserves in woody tissues. He found that in late autumn the starch in the cortical region was converted into sugar and in early spring it was reconverted into starch. Lidforss (28) examined a wide range of species of wintergreen plants in southern Sweden, and found that the leaf tissue usually was entirely free from starch during winter. He also recognized that certain plants do not store starch but only sugar. He further found that submerged aquatic plants which never reached 0.0° C. contained starch throughout their tissues. Those which float on the surface of the water showed no starch in the upper epidermis and little in the mesophyll, while the lower epidermis and adjacent tissue were rich in starch. Fischer found that the iris rootstock was starch-free in the periphery, but internally starch was abundant during winter. From Lidforss' work the theory (advanced later by Schaffnit, 40, 41, 42) was evolved that sugar has a protective effect against the precipitation of plant proteins. An examination of Table VIII and Charts II and III reveals that in general the change from starch to sugar takes place in alfalfa roots, as shown by the higher sugar content, during the winter months. Zacharowa (51), in examining non-hardened seedling root tissues, presents data which he

uses to refute Lidforss' theory relative to the protective effect of sugar against protein precipitation. The phenomenon of sugar formation has been examined by Fischer and shown to be the result of temperature change. He reports 5.0° C. as a starch regeneration minimum. Coville (12) advanced the following theory in explanation of the formation of sugar during the process of chilling: "The starch grains stored in the cells of the plant are at first separated by the living and active cell membranes from the enzyme that would transform the starch into sugar, but when the plant is chilled the vital activity of the cell membrane is weakened so that the enzyme 'leaks' through it, comes in contact with the starch, and turns it into sugar." Apelt (2), in his investigation on the freezing of potato tubers, found that the increase in sugar content resulting from previous exposure to cold above freezing was too small to account for the increased freezing point depression. Apelt's results agree with those of Rein (37).

When the total sugars are calculated in terms of total carbohydrates (Table IX and Chart III, Figure D) it appears that the sugar ratio is practically doubled in winter. By comparing the percentages of the two varieties, it is seen that the Grimm variety contains a relatively higher percentage of sugar. This may be sufficient to be considered as one point of advantage on the assumption that sugar acts as a protective colloid. Since reducing sugars are practically equal in the two varieties under consideration, this can not be used as a point of differentiation. A well known exception to Lidforss' theory of the protective action of sugar is found in the sugar beet, which is not winter hardy.

Pentosan content has been correlated with hardiness by Hooker (26) and Rosa (38). This, however, has been refuted recently by McGinty (30). From the data here presented, no significant difference in pentosan content exists between varieties. While there is an increase in April and May, based on dry weight, it is also shown that other carbohydrate reserves are low. This appears to indicate a difference in their availability during this active growth period as compared with starch and sugar. Spoehr (43) has shown that in cacti low water content and high temperature are associated with pentosan content. He arrives at the conclusion that under stress the plant possesses the power of utilizing the reserve polysaccharides, including pentosans. Under unfavorable conditions the latter carbohydrates will be utilized. The data indicate that this occurs in alfalfa. As the more available hexoses and hexosans are utilized first, it seems logical that the less available pentosans should increase on a dry weight basis during early spring growth.

TABLE IX

CARBOHYDRATES IN ALFALFA ROOTS EXPRESSED IN PERCENTAGES OF TOTAL CARBOHYDRATES

Date	Kansas				Grimm			
	Total carbohydrates	Total sugar in terms of total carbohydrates	Reducing sugar based on total sugar	Pentosans based on total carbohydrates	Total carbohydrates	Total sugar in terms of total carbohydrates	Reducing sugar based on total sugar	Pentosans based on total carbohydrates
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
10/19/22	53.36	22.3	...	...	45.96	35.8	...	...
12/26/22	45.01	44.0	...	...	42.61	57.1	...	...
4/ 6/23	58.37	53.0	...	...	40.98	52.1	...	...
4/23/23	34.68	45.5	...	...	32.07	48.9	...	...
5/ 5/23	25.56	24.6	...	...	28.34	28.8	...	...
5/19/23	34.99	36.2	...	...	41.42	39.0	...	...
7/26/23	45.17	30.4	...	17.6	43.08	27.1	...	20.6
8/ 7/23	40.78	35.4	...	...	36.71	36.1	...	...
10/ 2/23	37.84	40.5	...	...	41.38	31.9	...	...
10/30/23	47.66	40.2	34.3	19.8	39.03	45.5	39.2	20.9
11/10/23	38.80	53.4	22.7	26.7	33.23	31.1	17.3	29.2
12/21/23	43.02	53.1	7.1	20.7	36.65	64.8	9.8	21.4
1/23/24	45.39	59.7	10.0	21.7	44.82	64.7	6.7	22.0
2/ 4/24	46.43	55.7	8.2	22.1	39.23	62.8	4.7	25.5
3/13/24	48.22	54.4	7.1	21.8	42.42	60.6	6.9	26.4
3/24/24	50.49	57.6	11.8	23.8	47.77	58.6	12.3	25.7
4/ 2/24	45.45	46.2	32.6	22.5	41.85	54.1	35.5	25.3
4/21/24	35.46	45.1	13.3	38.8	37.65	43.9	13.5	35.1
5/17/24	32.46	29.1	17.7	39.4	32.31	27.5	23.4	44.2
2/ 7/25	43.01	55.8	15.1	22.1	41.84	56.8	14.6	27.3

NITROGENOUS MATERIALS IN RELATION TO OVERWINTERING IN ALFALFA

The total organic nitrogen in the dry weight residue, available for a limited number of samples only, is useful to compare the amino-nitrogen to the total organic nitrogen. In this way it is possible to arrive at an estimate of the relative amount of protein splitting which occurred during winter. The data are presented in Table X and Chart IV.

Amino-nitrogen.—The amino-nitrogen content was found not to vary greatly as the season progressed, as is shown in Table X and Chart IV, Figure B. Such fluctuations as occur are of doubtful significance in relation to winter hardiness of the varieties under study. Gorke (19) was the first to emphasize the precipitation of proteins as a cause for the death of the cell. He showed that this was brought about by increasing the cell sap concentration and its acidity. He found that the precipitation varied with the temperature and hardiness of the plant. Schaffnit (40) ascribed the protection to the splitting of complex proteins into less readily precipitated forms. Later, Schander and Schaffnit (42) restate the hypothesis and relate it to the winter hardiness of cereals. Harvey (23) found an increase in the amino-acid content of hardened cabbage. Newton (34) found a slight increase in the amino-nitrogen content between October and December of all wheat varieties studied. He points out that it appears to be characteristic of all varieties without regard to hardiness. The data cited from other investigators deal with tissues from above-ground parts. In this investigation subterranean parts are involved and, as previously shown, they are not subject to as low temperatures or to the same fluctuations of temperature as the parts above ground. It appears that the same phenomena do not occur under the environment provided by the soil.

The organic nitrogen, which is soluble in alcohol, fluctuates somewhat. However, there is no indication that appreciable amounts of it change to the amino form as a result of low temperature prevailing during the winter months. Thus, this determination does not give a quantitative difference between varieties examined.

The extreme precautions taken by Schander and Schaffnit to prevent any changes in the cell proteins due to temperature were not possible in the preparation of the material for this study. However, with the data at hand, it seems doubtful whether protein splitting exists, if at all, in sufficient degree to function as a means of protection against winterkilling of alfalfa roots. It is also recognized that the alfalfa root is not subjected to wide fluctuations in temperature, especially when covered with snow.

TABLE X

EFFECT OF ENVIRONMENT UPON SOLUBLE NITROGEN IN ALFALFA ROOTS

Date	Kansas				Grimm			
	Alcohol soluble nitrogen dry weight basis	Amino-nitrogen dry weight basis	Total organic nitrogen dry weight basis	Ratio of amino-nitrogen to total organic nitrogen	Alcohol soluble nitrogen dry weight basis	Amino-nitrogen dry weight basis	Total organic nitrogen dry weight basis	Ratio of amino-nitrogen to total organic nitrogen
	Per cent	Per cent	Per cent		Per cent	Per cent	Per cent	
10/19/22	0.72	0.39	...		0.76	0.45	...	
12/26/22	0.87	0.66	...		1.08	0.72	...	
4/23/23	0.77	0.62	...		1.02	0.67	...	
5/ 5/23	0.45	0.52	...		0.37	0.47	...	
7/26/23	0.63	0.41	...		0.73	0.40	...	
8/ 7/23	0.84	0.51	...		0.86	0.47	...	
10/30/23	0.71	0.40	...		0.85	0.41	...	
11/10/23	0.88	0.44	2.93	0.150	0.68	0.46	2.48	0.185
12/21/23	0.48	0.43	2.84	0.151	0.71	0.54	2.68	0.201
1/23/24	0.46	0.31	2.34	0.134	0.61	0.37	2.82	0.131
2/ 4/24	0.53	0.38	3.18	0.119	0.71	0.50	2.49	0.201
3/13/24	0.63	0.43	2.54	0.169	0.94	0.43	3.21	0.134
3/24/24	0.75	0.46	2.99	0.154	0.88	0.43	3.10	0.139
4/ 2/24	0.73	0.39	2.95	0.132	0.94	0.45	3.09	0.146
4/21/24	0.87	0.57	...		0.76	0.49	...	
5/17/24	...	0.33	...		...	0.41	...	
2/ 7/25	0.65	0.48	2.69	0.178	0.66	0.50	2.62	0.191

SUMMARY

1. A study has been made of the relative winter hardiness of Grimm and of common Kansas alfalfa. Several available methods have been used with the hope of ascertaining ready means for distinguishing hardy and non-hardy types.

2. Alfalfa plants have no autonomous rest period. The plants came into active growth within 3 days when brought into the greenhouse during every month in which growth is not possible in the field. The plants are forced into inactivity by unfavorable environmental conditions.

3. The varieties under study have a critical period during the early spring interval when the snow disappears and the soil thaws.

4. Resistance to cold increases in the roots of both varieties as winter approaches and disappears with the approach of spring.

5. Temperatures taken at the surface of the soil beneath the snow indicate that snow provides ample protection for alfalfa plants against killing by low temperatures.

6. Freezing injury results in the destruction of the central part of the root and leaves it susceptible to infection by decay organisms. The crown buds are more hardy than the root tissues immediately below them.

7. The thermo-electric method has been used in determining the freezing points of root tissues. It is a rapid method of making determinations but, in general, was not reliable for differentiating between hardy and nonhardy varieties.

8. No absolute correlation exists between the degree of freezing point depression and resistance to killing by freezing.

9. Sap was expressed from the roots and physical determinations were made upon it. The results are summarized here:

a. The quantity of press juice obtained from 100 grams of material at the respective pressures bears no apparent relation to the hardiness of varieties.

b. The total solids in the sap are correlated with total dry matter in the root tissue, but apparently are not correlated with hardiness.

c. Viscosity is related to total solids in the sap but apparently not to hardiness.

10. The alfalfa root undoubtedly functions as a storage structure for carbohydrate and possibly for small amounts of protein reserves.

11. There is a transformation of starch into sugar during the late autumn and early winter and apparently a partial reconversion in early spring, in accordance with the principle of Fischer.

12. It has been found that the hardy variety has more sugar, expressed in terms of total carbohydrates, than the less hardy variety. Accepting the theory that sugar acts as a protective colloid, the hardy variety appears to have a point of advantage.

13. Pentosans have been determined on samples collected during one year, with the result that no apparent quantitative relation exists between pentosan content and hardiness.

14. The amino-nitrogen fluctuations do not indicate that protein cleavage is of importance in the protection of proteins against precipitation.

15. As positive measures of the differences between the varieties under study, the freezing of potted plants or roots removed from the soil has been found to be the most practical and reliable method. Undoubtedly a set of standards could be constructed, based upon the degrees of root injury, which would provide a practical basis for classifying alfalfa strains or varieties into hardiness groups.

LITERATURE CITED

1. Abbe, C. The influence of cold on plants—a resumé. U. S. Dept. of Agr. Exp. Sta. Rec. **6**:777-781. 1895.
2. Apelt, Arthur. Neue Untersuchungen über den Kältetod der Kartoffel. Cohn's Beitr. Biol. der Pflanzen **9**:215-262. 1909.
3. Arny, A. C. Winterhardiness of medium red clover strains. Jour. Amer. Soc. Agron. **16**:268-278. 1924.
4. D'Arsonval, M. La pression osmotique et son rôle de defense contre le froid dans la cellule vivante. Compt. Rend. Acad. Sci. Paris **133**:84-86. 1901.
5. Blackman, F. F. Vegetation and frost. New Phytol. **8**:354-363. 1909.
6. Brand, C. J. The acclimatization of an alfalfa variety in Minnesota. Science, N.S. **28**:891-892. 1908.
7. ——— and Waldron, L. R. Cold resistance of alfalfa and some factors influencing it. U. S. Dept. of Agr., B. P. I. Bul. 185. 1910.
8. ———. Grimm alfalfa and its utilization in the northwest. U.S. Dept. of Agr., B.P.I. Bul. 209. 1911.
9. Bristol, B. Muriel and Page, H. J. A critical enquiry into the alleged fixation of nitrogen by green algae. Ann. of App. Biol. **10**:378-408. 1923.
10. Carrick, D.B. Resistance of the roots of some fruit species to low temperature. Cornell Agr. Exp. Sta. Mem. 36. 1920.
11. Chandler, W. H. The killing of plant tissue by low temperature. Mo. Agr. Exp. Sta. Res. Bul. 8. 1913.
12. Coville, F. V. The influence of cold in stimulating the growth of plants. Jour. Agr. Res. **20**:151-160. 1920.
13. Davis, William A., Daish, A. J., and Sawyer, G. C. Studies of the formation and translocation of carbohydrates in plants. Jour. Agr. Sci. **7**:255-326. 1916.
14. Dixon, H. H. and Atkins, W. R. G. On osmotic pressure in plants; and on a thermo-electric method of determining freezing points. Sci. Proc. Roy. Dub. Soc. **12**:275-311. 1910.

15. ————. Osmotic pressure in plants: I. Methods of extracting sap from plant organs. Sci. Proc. Roy. Dub. Soc. **13**:422-433. 1913.
16. Fischer, Alfred. Beitrage zur Physiologie der Holzgewächse. Jahrbücher für Wissenschaftliche Botanik **22**:73-160. 1891.
17. Goeppert, H. R. Über die Wärme-Entwickelung in den Pflanzen deren Gefrieren und die Schutzmittel gegen dasselbe. Breslau. 1830.
18. ————. Höhe der Kältegrad, welche die Vegetation überhaupt erträgt. Bot. Zeitg. **29**:48-58, 64-75. 1871.
19. Gorke, H. Über chemische Vorgänge beim Erfrieren der Pflanzen. Landw. Vers. Sta. **65**:149-160. 1907. Abst. in Jour. Chem. Soc. **90**:798. 1906.
20. Gortner, R. A., Lawrence, J. V., and Harris, J. A. The extraction of sap from plant tissues by pressure. Biochem. Bul. **5**:139-143. 1916.
21. Gortner, R. A. and Hoffman, W. F. Determination of the moisture content of expressed plant tissue fluids. Bot. Gaz. **74**:308-313. 1922.
22. Harris, J. Arthur and Gortner, R. A. Notes on the calculation of the osmotic pressure of expressed vegetable saps from the depression of the freezing point, with a table for the values of P for $\Delta = 0.001°$ to $\Delta = 2.999°$ C. Amer. Jour. Bot. **1**:75-78. 1914.
23. Harvey, R. B. Hardening process in plants and developments from frost injury. Jour. Agr. Res. **15**:83-112. 1918.
24. ————. Importance of epidermal coverings. Bot. Gaz. **67**:441-444. 1919.
25. ———— and Regeimbal, L. O. Relation of mean temperature to the freezing points and killing points of trees and shrubs. Proc. Amer. Assoc. Adv. Sci. Plant Physiol. Sec. Toronto. 1921.
26. Hooker, H. D. Pentosan content in relation to winter hardiness. Proc. Amer. Soc. Hort. Sci. 1920. 204-207. 1920.
27. Horne, W. D. Dry defecation in optical sugar analysis. Jour. Amer. Chem. Soc. **26**:186-192. 1904.
28. Lidforss, Bengt. Zur Physiologie und Biologie der wintergrünen Flora. Separat-Ausdruck aus Botanischer Centralblatt. Bd. 68. Jena. 1896.
29. Maximow, N. A. Chemische Shutzmittel der Pflanzen gegen Erfrieren Berichte Deutsch. Bot. Gesellschaft **30**:52-65. 1912.
30. McGinty, R. A. Preliminary notes on the tip burn of lettuce. Proc. Amer. Soc. Hort. Sci. 1925. 341-346. 1925.
31. Nelson, N. T. The effects of frequent cutting on the production, root reserves and behavior of alfalfa. Jour. Amer. Soc. Agron. **17**:100-113. 1925.
32. Newton, Robert. A comparative study of winter wheat varieties with especial reference to winterkilling. Jour. Agr. Sci. **12**:1-19. 1922.
33. ———— and Gortner, R. A. A method for estimating hydrophyllic colloid content of expressed plant tissue fluids. Bot. Gaz. **74**:442-446. 1922.
34. ————. The nature and practical measurement of frost resistance in winter wheat. Univ. Alberta Coll. Agr. Res. Bul. 1. 1924.
35. ————. Brown, W. R., and Martin, W. M. The extraction of plant tissue fluids and their utility in physiological studies. Plant Physiol. **1**:57-65. 1926.
36. Payne, Nellie M. Freezing and survival of insects at low temperatures. A thesis. Univ. of Minn. 1925.
37. Rein, Richard. Untersuchungen über den Kältetod der Pflanzen. Zeitschr. für Naturwiss. **80**:1-38. 1908.
38. Rosa, J. T., Jr. Investigations on the hardening process in vegetable plants. Mo. Agr. Exp. Sta. Res. Bul. 48. 1921.

39. Scatchard, G. The hydration of sucrose in water solution as calculated from vapor-pressure measurements Jour. Amer. Chem. Soc. **43**:2406-2418. 1921.
40. Schaffnit, E. Studien über den Einfluss niederer Temperaturen auf die pflanzliche Zelle. Mitt. Kaiser Wihelms Inst. Landw. Bromberg **8**:93-144. 1910.
41. ————. Über den Einfluss niederer Temperaturen auf die pflanzliche Zelle. Zeitschr. für Allgemeine Physiologie **12**:323-336. 1911.
42. Schander, R. and Schaffnit, E. Untersuchungen über das Auswintern des Getreides. Landw. Jahrb. **52**:1-66. 1918.
43. Spoehr, Herman A. The carbohydrate economy of cacti. Carnegie Inst. Wash. Pub. 287. 1919.
44. Sylvén, Nils. Övervintring och återväxt hos blåluzern i försök på Svalöf. Sveriges Utsadesförenings Tidskrift **35**:162-176. 1925.
45. Van Slyke, D. D. The analysis of proteins by determination of the chemical groups characteristic of the different amino-acids. Jour. Biol. Chem. **10**:15-55. 1911.
46. Wahlen, Fritz. Researches in the overwintering of perennial legumes. Landwirtschaft. Jahrb. der Schweitz. Heft2:103-133. 1923. Abst. U.S. Dept. of Agr. Exp. Sta. Rec. **50**:333-334. 1924.
47. White, Walter P. The thermoelement as a precision thermometer. Phys. Rev. **31**:135-158. 1910.
48. Wiegand, K. M. The occurrence of ice in plant tissue. Plant World **9**:25-38. 1906.
49. Winkler, Albert. Über den Einfluss der Ausenbedingungen auf die Kälteresistenz ausdauernder Gewäsche. Jahrb. für Wissenschaft. Bot. **52**:467-506. 1913.
50. Young, Vernon. Winter hardiness of alfalfa. Thesis. Iowa State College. pp. 1-185. 1924.
51. Zacharowa, T. M. Über den Einfluss niedriger Temperaturen auf die Pflanzen. Jahrb. für Wissenschaft. Bot. **65**:61-87. 1925.

TECHNICAL BULLETIN 39 JULY 1926

University of Minnesota
Agricultural Experiment Station

Tables for Determining Contents of Standing Timber in Minnesota, Michigan, and Wisconsin

Compiled by
Cloquet Forest Experiment Station
Division of Forestry
and
Lake States Forest Experiment Station,
Forest Service, U.S. Department of Agriculture

UNIVERSITY FARM, ST. PAUL

INDEX TO VOLUME TABLES

Species and Unit of Measure	Table No.	Page
Ash, black (*Fraxinus nigra*):		
Board measure—		
Scribner Decimal C	1	7
Do	2	8
Cords—		
Total volume	3	9
Cubic feet—		
Peeled volume	4	10
Ash, white (*Fraxinus americana*):		
Board measure—		
Scribner Decimal C	5	11
Do	6	12
Cords—		
Total volume	7	13
Cubic feet—		
Peeled volume	8	14
Do	9	15
Aspen (*Populus tremuloides*):		
Board measure—		
International ¼-inch kerf	10	16
Scribner Decimal C	11	17
Cords—		
Merchantable volume	12	18
Cubic feet—		
Total volume	13	19
Merchantable volume	14	20
Balsam fir (*Abies balsamea*):		
Board measure—		
Scribner	15	21
Do	16	22
Cords—		
Total volume	17	23
Cubic feet—		
Total volume	18	24
Do	19	25
Merchantable volume	20	26
Do	21	27
Basswood (*Tilia glabra*):		
Board measure—		
Scribner Decimal C	22	28
Cords—		
Total and merchantable volume	23	29
Cubic feet—		
Total and merchantable volume	24	30
Beech (*Fagus grandifolia*):		
Board measure—		
Scribner Decimal C	25	31
Cords—		
Total and merchantable volume	26	32
Cubic feet—		
Total and merchantable volume	27	33
Birch, paper (*Betula papyrifera*):		
Cords—		
Merchantable volume	28	34
Cubic feet—		
Total volume	29	35
Merchantable volume	30	36
Birch, yellow (*Betula lutea*):		
Board measure—		
Scribner Decimal C	31	37
Cords—		
Total volume	32	38
Cubic feet—		
Total volume	33	39

INDEX TO VOLUME TABLES—Continued

Species and Unit of Measure	Table No.	Page
Cedar, northern white (*Thuja occidentalis*):		
Board measure—		
Scribner	34	40
Cubic feet—		
Total volume	35	41
Merchantable volume	36	42
Cottonwood (*Populus deltoides*):		
Board measure—		
Scribner Decimal C	37	43
Do	38	44
Cubic feet—		
Peeled volume	39	45
Elm (*Ulmus americana*):		
Board measure—		
Scribner	40	46
Hardwoods, mixed		
Cubic feet—		
Total	41	47
Hemlock, eastern (*Tsuga canadensis*):		
Board measure—		
Scribner Decimal C	42	48
Do	43	49
Cords—		
Merchantable volume	44	50
Cubic feet—		
Merchantable volume	45	51
Hickory (*Hicoria sp.*):		
Cubic feet—		
Total volume	46	52
Merchantable volume	47	53
Maple, red (*Acer rubrum*):		
Cords—		
Merchantable volume	48	54
Cubic feet—		
Merchantable volume	49	55
Maple, sugar (*Acer saccharum*):		
Board measure—		
Scribner	50	56
Scribner Decimal C	51	57
Cords—		
Total and merchantable volume	52	58
Cubic feet—		
Total and merchantable volume	53	59
Oaks, red, black, and scarlet (*Quercus*):		
Cubic feet—		
Total volume	54	60
Ties—		
Total volume	55	61
Oak, red (*Quercus borealis maxima*):		
Board measure—		
Scribner Decimal C	56	62
Do	57	63
Oak, white (*Quercus alba*):		
Board measure—		
Scribner Decimal C	58	64
Cubic feet—		
Total volume	59	65
Cubic feet per cord	60	66

INDEX TO VOLUME TABLES—Continued

Species and Unit of Measure	Table No.	Page
Pine, Jack (*Pinus banksiana*):		
Board measure—		
International ⅛-inch kerf	61	67
Scribner Decimal C	62	68
Do	63	69
Cords—		
Merchantable volume	64	70
Cubic feet—		
Total volume	65	71
Merchantable volume	66	72
Ties	67	73
Pine, red (*Pinus resinosa*):		
Board measure—		
Scribner Decimal C	68	74
Do	69	75
Cubic feet—		
Peeled volume	70	76
Total, exclusive of stump	71	77
Pine, white (*Pinus strobus*):		
Board measure—		
Scribner	72	78
Scribner Decimal C	73	79
Do	74	80
Cords—		
Merchantable volume	75	81
Cubic feet—		
Total volume	76	82
Spruce, black (*Picea mariana*):		
Cords—		
Merchantable volume	77	83
Cubic feet—		
Total volume	78	84
Do	79	85
Merchantable volume	80	86
Do	81	87
Spruce, white (*Picea glauca*):		
Cords—		
Merchantable volume	82	88
Cubic feet—		
Total volume	83	89
Do	84	90
Do	85	91
Do	86	92
Merchantable volume	87	93
Do	88	94
Do	89	95
Tamarack (*Larix laricina*):		
Board measure—		
Scribner Decimal C	90	96
Do	91	97
Cubic feet—		
Peeled volume	92	98
Ties	93	99

INTRODUCTION

A knowledge of the contents of standing trees, whether in board measure, cubic feet, cords, ties, or other forest products is basic to any woods operation. Tables showing the contents of average trees of given sizes according to some unit of measure are known as **volume tables.** Such tables are used in estimating the amount of standing timber for purposes of purchase or sale and for logging operations; and to determine the stand and growth of timber for the purpose of appraisal of fire damage, trespass, and forest valuation, and management in general; and also for all kinds of scientific studies involving volume, growth, and yield. The need of volume tables is therefore apparent.

The purpose of this bulletin is to bring together in a handy and readily available form the volume tables for the forest trees of the Lake States—Michigan, Wisconsin, and Minnesota. Some 93 volume tables, covering 25 species, have been included. Of these, 31 tables have not been published hitherto and for 15 tables the actual field data were collected and the computations made by the Cloquet and Lake States Forest Experiment Stations.

Very few or no volume tables for the Lake States region are as yet available for such species as balsam; white cedar; cottonwood; elm; hickories; red maple; black, bur, red, scarlet, and white oaks; second-growth red and white pines; and black spruce. As these are important commerical species in the Lake States, it was thought advisable, at least for the present, to include for these species volume tables prepared in other regions, as the Northeast. These tables may be too high or too low for local conditions in the Lake States. They are, however, the best that are available at present, and if used with occasional checks, may prove serviceable.

The volume tables in this bulletin are not equally reliable. Some are not based on a sufficiently large number of trees to be fully representative of all conditions. Others were not compiled with the same thoroness or by the same methods and therefore are not truly comparable. On each table, the number of trees upon which it is based, the locality in which the data were collected, the name of the person who collected the field data, and the compilor of the table, if it were not done by the same person, are indicated. Other information is given that may prove helpful in an intelligent application of the tables.

All volume tables have limitations and their use requires judgment and knowledge of conditions under which they are to be applied.

Volume tables are based on measurements taken on a large number of felled trees. The values given are therefore average values. It can not be expected that a single tree taken at random will have the exact contents given in the table. It is only by applying the average values to a large number of trees that a fairly reliable estimate of the contents of standing timber can be secured.

To apply volume tables for standing trees the diameter, height, or number of logs, of each tree for a given species, must be determined first. The values corresponding to these diameters and heights or number of logs, are found in the table based on the desired unit of measure and the degree of utilization to which it is expected the stand will be cut. The diameters are measured outside of bark at 4½ feet above the ground. They may be measured with a diameter tape, calipers, or cruisers sticks, or, as is the custom with experienced estimators, by eye. Heights are obtained by estimate or by use of a height-measuring instrument.

In making available the volume tables for the Lake States region for use of lumbermen, foresters, botanists, and other students of forest trees, the aim is to provide the first step toward a gradual improvement in our methods of determining the contents of forest stands. It is hoped that these tables will be checked in actual field use and any serious deviations from actual conditions observed and corrected and new tables compiled for species for which no tables exist.

Table 1

BLACK ASH

(*Fraxinus nigra*)

New Hampshire, New York, Michigan, Indiana

Sterrett
Barrows **1912** Scribner Decimal C

Diameter breast high	Total height of tree—feet						Diameter inside bark of top	Basis
	60	70	80	90	100	110		
	Volume—board feet, in tens							
Inches							*Inches*	*Trees*
8	2.6	3.5	4.7				6	4
9	3.7	5.0	6.2				6	6
10	5.0	6.5	7.9				6	8
11	6.1	8.1	9.7				6	5
12	7.6	9.9	12	15			6	10
13	9.1	12	14	18			6	16
14	11	14	17	21			6	4
15	13	16	20	24			6	9
16	15	19	23	27	31		6	12
17	17	22	27	31	36		6	4
18	20	26	31	35	40	44	6	7
19		30	35	39	45	49	6	5
20		34	40	44	50	55	6	3
21		39	45	49	56	61	7	8
22		44	50	55	62	68	7	2
23		49	56	62	68	75	8	2
24		55	62	69	76	82	9	1
25			68	76	84	91	9	2
26			74	83	92	100	10	1
27			81	91	100	109	10	1
28			88	99	109	119	11	1
29			95	106	118	129	11	1
30			103	114	127	139	12	1
31			110	123	136	150	13	
32			117	131	146	160	13	
Total								114

Trees 75 to 300 years old. Stump height, 1 foot. Based on taper curves scaled mostly as 16.3-foot logs, with a few shorter logs where necessary. Trees from Grafton County, N. H.; Franklin County, N. Y.; Ontonagon County, Mich.; and Wayne County, Ind.

Table 78, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 2

BLACK ASH

(*Fraxinus nigra*)

New Hampshire, New York, Michigan, Indiana

Sterrett
Barrows — **1912** — Scribner Decimal C

Diameter breast high	Number of 16-foot logs									Diameter inside bark of top	Basis
	2	2½	3	3½	4	4½	5	5½	6		
	Volume—board feet, in tens										
Inches										*Inches*	*Trees*
8	3.8	5.2	6.5							6	4
9	4.2	5.7	7.2							6	6
10	4.7	6.3	8	10						6	8
11	5.3	7	9	12						6	5
12	5.9	8	10	13	16					6	10
13	6.6	9	11	15	18					6	16
14	7.4	10	13	17	20	23				6	4
15	8.3	11	15	19	23	26				6	9
16	9.3	13	17	21	25	29	34			6	12
17		14	19	24	28	33	37			6	4
18		16	21	27	32	36	42	46		6	7
19		18	24	30	36	40	46	51		6	5
20		19	27	34	40	45	51	57	61	6	3
21			30	38	44	50	57	63	68	7	8
22			34	43	50	56	63	70	75	7	2
23			38	49	56	63	70	77	83	8	2
24			43	55	63	71	77	85	92	9	1
25				62	70	79	86	94	102	9	2
26				69	78	87	95	103	112	10	1
27				77	86	96	104	113	122	10	2
28				85	95	105	114	124	134	11	1
29				93	104	114	124	135	145	11	1
30				102	113	123	134	146	157	12	1
Total											114

Trees 75 to 300 years old. Stump height, 1 foot. Based on taper curves compiled by W. B. Barrows; scaled mostly as 16.3-foot logs, with a few shorter logs where necessary. Trees from Grafton County, N. H.; Franklin County, N. Y.; Ontonagon County, Mich.; and Wayne County, Ind.

Table 46, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 3

BLACK ASH

(*Fraxinus nigra*)

New Hampshire, New York, Michigan, Indiana

Sterrett
Barrows

1912

Cords

Diameter breast high	Total height of tree—feet						Bark	Basis
	60	70	80	90	100	110		
	Volume—cords							
Inches							*Per ct.*	*Trees*
6	.066	.077	.088				18.0	
7	.088	.103	.117				17.6	2
8	.114	.133	.152				17.2	4
9	.143	.167	.190				16.8	6
10	.179	.208	.238				16.4	8
11	.212	.248	.283				16.0	5
12	.253	.296	.338	.381			15.7	10
13	.293	.342	.391	.440			15.3	16
14	.341	.398	.454	.511			14.9	4
15	.388	.453	.518	.583			14.5	9
16	.442	.516	.590	.663	.737		14.2	12
17	.495	.578	.660	.742	.825		13.8	4
18	.554	.647	.739	.832	.923		13.5	7
19		.714	.815	.918	1.019		13.1	5
20		.790	.903	1.015	1.128	1.241	12.8	3
21		.865	.990	1.113	1.236	1.360	12.4	8
22		.948	1.083	1.219	1.354	1.490	12.1	2
23		1.028	1.175	1.322	1.469	1.617	11.8	2
24		1.118	1.277	1.437	1.597	1.756	11.4	1
25			1.375	1.547	1.718	1.891	11.1	2
26			1.487	1.673	1.859	2.046	10.8	1
27			1.605	1.805	2.006	2.206	10.5	2
28			1.711	1.924	2.138	2.352	10.2	1
29			1.834	2.063	2.293	2.582	9.9	1
30			1.962	2.208	2.453	2.697	9.6	1
Total								116

To reduce to cubic feet, including stump, multiply the number of cords in each case by 100.

Volume includes bark. Based on taper tables compiled by W. B. Barrows. Trees 75 to 300 years old.

Table 45, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 4

BLACK ASH

(*Fraxinus nigra*)

New Hampshire, New York, Michigan, Indiana

Sterrett
Barrows **1912** Cubic feet

Diameter breast high	Total height of tree—feet						Factors to multiply by to convert to cu. ft., including bark	Basis
	60	70	80	90	100	110		
	Peeled volume—cubic feet							
Inches								*Trees*
6	5.4	6.3	7.2				1.22	
7	7.3	8.5	9.7				1.21	2
8	9.4	11.0	12.6				1.21	4
9	11.9	13.9	15.8				1.20	6
10	14.9	17.3	19.8				1.20	8
11	17.8	21.0	24.0				1.19	5
12	21.0	25.0	28.0	32			1.19	10
13	25.0	29.0	33.0	37			1.18	16
14	29.0	34.0	39.0	43			1.18	4
15	33.0	39.0	44.0	50			1.17	9
16	38.0	44.0	50.0	57	63		1.17	12
17	43.0	50.0	57.0	64	71		1.16	4
18	48.0	56.0	64.0	72	80		1.16	7
19		62.0	71.0	80	89		1.15	5
20		69.0	78.0	88	98	108	1.15	3
21		76.0	87 0	98	108	119	1.14	8
22		83.0	95.0	107	119	131	1.14	2
23		91.0	104.0	117	130	143	1.13	2
24		99.0	113.0	127	141	155	1.13	1
25			123.0	138	153	169	1.12	2
26			133.0	149	166	183	1.12	1
27			143.0	161	179	197	1.12	1
28			154.0	173	193	212	1.11	1
29			165.0	186	207	227	1.11	1
30			177.0	199	221	243	1.11	1
Basis								116

Volume in cubic feet of stem wood, exclusive of bark.
Based on taper curves.
Trees 75 to 300 years old.
Table 44, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 5

SECOND-GROWTH WHITE ASH

(Fraxinus americana)

Vermont, New York, Michigan, Indiana, Tennessee

Sterrett
Barrows — **1912** — Scribner Decimal C

Diameter breast high	Total height of tree—feet								Diameter inside bark of top	Basis
	30	40	50	60	70	80	90	100		
	Volume—board feet, in tens									
Inches									*Inches*	*Trees*
8	0.5	0.8	1.3	1.9	2.5	3.2	3.9		6	80
9	0.8	1.4	2.0	2.9	3.7	4.7	5.7		6	57
10	1.2	2.0	2.7	4.0	4.9	6.4	7.6	9.1	6	63
11	1.7	2.6	3.6	5.0	6.3	8.1	9.7	11	6	54
12	2.2	3.4	4.7	6.4	7.9	10	12	14	6	45
13	2.8	4 3	5.8	7.8	9.6	12	14	17	6	33
14	3.5	5 2	7.0	9.3	12	14	17	20	6	28
15		6.3	8.5	11	14	17	20	23	6	19
16		7.3	9.9	13	16	19	23	26	6	14
17			12	15	19	22	26	30	6	10
18			13	17	21	25	29	33	6	6
19			15	19	24	28	33	38	6	6
20			17	22	27	32	37	42	6	3
21			19	24	30	35	41	47	7	4
22			21	27	33	39	46	52	7	1
Total										423.

Trees less than 75 years old. Stump height, 1 foot. Based on taper curves; scaled mostly as 16.3-foot logs, with a few shorter logs where necessary. Trees from Chittenden, Orange, Washington, and Windsor Counties, Vt.; Herkimer, Oswego, and Otsego, Counties, N. Y.; Montgomery and Wabash Counties, Ind.; Leelanau County, Mich.; and Stewart County, Tenn.

Table 82, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 6

WHITE ASH

(Frazinus americana)

Vermont, New York, Michigan, Indiana, Tennessee

Sterrett
Barrows **1912** Scribner Decimal C

Diameter breast high	Number of 16-foot logs									Diameter inside bark of top	Basis
	2	2½	3	3½	4	4½	5	5½	6		
	Volume—board feet, in tens										
Inches										*Inches*	*Trees*
8	3.2	4.3	5.1	6.9						6	13
9	3.7	5.0	6.0	8 0						6	23
10	4 2	5.8	7.0	9.1						6	28
11	4.9	6.8	8.0	10						6	42
12	5.7	7.8	9.3	12	14					6	49
13	6.6	9.0	11	13	16					6	46
14	7.7	10	12	15	18	20	23			6	51
15	9.0	12	14	17	20	23	26			6	32
16	10	13	16	19	22	26	29	33	37	6	51
17	12	15	18	21	25	29	33	37	41	6	30
18	13	17	20	24	28	32	37	41	46	6	24
19	15	19	23	27	32	36	42	46	52	6	21
20	17	21	25	30	36	41	47	52	59	6	17
21	19	23	28	34	40	46	52	59	66	7	10
22	21	26	31	38	45	51	59	66	75	7	11
23		29	35	42	50	58	66	75	84	8	7
24		32	38	46	55	65	74	84	94	9	1
25		35	42	51	61	73	83	94	105	9	5
26		38	46	57	68	81	92	105	117	10	2
27		41	51	63	76	89	102	116	130	10	2
28		45	56	69	84	98	113	128	144	11	2
29		48	61	76	92	107	124	141	159	11	3
30		52	66	83	101	117	136	155	175	12	1
31			72	90	110	128	149	169	191	13	2
32			79	99	119	139	162	185	208	13	1
33			86	107	129	151	176	202	226	14	
34			93	116	140	164	191	220	247	14	
35			100	125	150	176	205	238	269	15	1
36			108	134	161	189	221	256	290	16	
37			116	144	172	202	236	274	312	16	
38			124	154	183	216	252	293	335	17	
39			132	165	195	231	269	313	362	17	
40			141	176	206	247	287	334	390	18	
Basis											475

Trees 75 to 150 years old. Stump height, 1 foot. Based on taper curves; scaled mostly as 16.3-foot logs, with a few shorter logs where necessary.
Table 37. U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 7

SECOND-GROWTH WHITE ASH

(*Fraxinus americana*)

Vermont, New York, Michigan, Indiana, Tennessee

Sterrett
Barrows **1912** **Cords**

Diameter breast high	Total height of tree—feet								Bark	Basis
	Total volume—cords									
Inches									*Per cent*	*Trees*
4	.009	.014	.017	.022	.026	.031			18.6	65
5	.013	.020	.027	.033	.040	.046	.054		18.3	70
6	.020	.028	.038	.048	.057	.067	.076		17.9	81
7		.039	.051	.064	.076	.090	.102	.115	17.6	57
8		.050	.067	.082	.099	.116	.132	.149	17.3	80
9		.061	.083	.103	.124	.144	.164	.185	17.0	57
10			.103	.128	.155	.180	.206	.232	16.7	63
11			.124	.155	.185	.216	.247	.278	16.4	54
12			.146	.183	.220	.257	.293	.330	16.1	45
13				.213	.256	.299	.342	.384	15.8	33
14				.247	.295	.345	.394	.444	15.5	28
15				.283	.340	.396	.453	.510	15.2	19
16				.322	.387	.451	.516	.579	15.0	14
17					.433	.504	.577	.649	14.7	10
18					.484	.565	.646	.727	14.4	6
19					.539	.629	.720	.808	14.2	6
20					.592	.690	.789	.887	13.9	3
21					.654	.763	.872	.981	13.7	4
22					.717	.836	.956	1.075	13.5	1
Total										696

Volume of stem, including bark.
To reduce to cubic feet, including stump, multiply the number of cords in each case by 100.
Trees under 75 years. Table based on taper curves.
Table 33, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 8

SECOND-GROWTH WHITE ASH

(*Fraxinus americana*)

Vermont, New York, Michigan, Indiana, Tennessee

Sterrett
Barrows

1912

Cubic feet

Diameter breast high	Total height of tree—feet								Factors to multiply by to convert to cubic feet including bark	Basis
	20	30	40	50	60	70	80	90		
	Peeled volume—cubic feet									
Inches										*Trees*
2	0.2	0.2	0.3							63
3	0.4	0.6	0.8							47
4	0.7	1.1	1.4	1.8	2.1	2.5			1.23	65
5	1.1	1.6	2.2	2.7	3.3	3.8			1.22	70
6	1.6	2.3	3.1	3.9	4.7	5.5	6.2		1.22	81
7		3.2	4.2	5.3	6.3	7.4	8.4		1.21	57
8		4.1	5.5	6.8	8.2	9.6	10.9	12.3	1.21	80
9		5.1	6.9	8.6	10.3	12.0	13.7	15.4	1.20	57
10			8.6	10.7	12.9	15.0	17.2	19.3	1.20	63
11			10.3	12.9	15.4	18.0	21.0	23.0	1.20	54
12			12.3	15.4	18.5	22.0	25.0	28.0	1.19	45
13				17.9	22.0	25.0	29.0	32.0	1.19	33
14				21.0	25.0	29.0	33.0	38.0	1.18	28
15				24.0	29.0	34.0	38.0	43.0	1.18	19
16				27.0	33.0	38.0	44.0	49.0	1.18	14
17					37.0	43.0	49.0	55.0	1.17	10
18					41.0	48.0	55.0	62.0	1.17	6
19					46.0	54.0	61.0	69.0	1.17	6
20					51.0	60.0	68.0	77.0	1.16	3
21					56.0	66.0	75.0	85.0	1.16	4
22					62.0	72.0	82.0	93.0	1.16	1
Total										806

Trees under 75 years. Based on taper tables. Stump height, 1 foot. Volume does not include bark.

Table 31, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 9

WHITE ASH

(*Fraxinus americana*)

Vermont, New York, Michigan, Indiana, Tennessee

Sterrett
Barrows **1912** Cubic feet

Diameter breast high	Total height of tree—feet								Factors to multiply by to convert to cubic feet, including bark	Basis
	50	60	70	80	90	100	110	120		
	Peeled volume—cubic feet									
Inches										*Trees*
6	4.0	4.8	5.6						1.38	5
7	5.4	6.5	7.6						1.36	8
8	7.0	8.4	9.8	11.2					1.34	13
9	8.8	10.6	12.3	14.1					1.32	23
10	11.0	13.2	15.4	17.6	19.8				1.31	28
11	13.2	15.8	18.5	21.	24.				1.30	42
12	15.8	19.	22.	25.	28.	32			1.28	49
13	18.4	22.	26.	29.	33.	37			1.27	46
14	21.	26.	30.	34.	39.	43	47		1.26	51
15	25.	30.	34.	39.	44.	49	54		1.25	32
16	28.	34.	39.	45.	50.	56	62	67	1.24	51
17	32.	38.	44.	51.	57.	63	70	76	1.23	30
18	35.	42.	50.	57.	64.	71	78	85	1.22	24
19	39.	47.	55.	63.	71.	79	87	95	1.21	21
20	44.	52.	61.	70.	78.	87	96	105	1.20	17
21	48.	58.	67.	77.	87.	96	106	116	1.19	10
22	53.	63.	74.	84.	95.	106	116	127	1.18	11
23		69.	81.	92.	104.	116	127	139	1.17	7
24		75.	88.	100.	113.	126	138	151	1.17	1
25		82.	95.	109.	123.	136	150	164	1.16	5
26		89.	103.	118.	133.	148	162	177	1.15	2
27			111.	127.	143.	159	175	191	1.15	2
28			120.	137.	154.	171	188	205	1.14	2
29			129.	147.	165.	184	202	220	1.14	3
30			137.	157.	177.	196	216	236	1.13	1
31				168.	189.	210	231	252	1.13	2
32				179.	201.	224	246	268	1.12	1
33				190.	214.	238	261	285		
34				202.	227.	252	278	303		
35				214.	240.	267	294	321		1
36				226.	255.	283	311	339		
Total										488

Trees from 75 to 150 years old. Based on taper tables. Stump height, 1 foot. Table excludes bark.
Table 32, U. S. Dept. of Agr. Bul. 299, The Ashes. W. D. Sterrett. 1915.

Table 10

SECOND-GROWTH ASPEN

(*Populus tremuloides*)

Minnesota

Gevorkiantz, S. R. **1926** International ⅛ inch kerf.

Diameter breast high	Number of 16-foot logs								Basis
	1	1½	2	2½	3	3½	4	4½	
	Volume—board feet								
Inches									*Trees*
6	15	20	26	31					43
7	15	24	32	40					42
8	15	27	39	50	60				47
9	15	30	44	58	74	90			37
10		34	51	68	86	104	122		36
11		37	58	79	100	120	144	167	22
12		41	66	92	118	144	171	198	26
13			75	106	138	170	202	233	23
14			86	123	161	199	237	274	18
15				142	186	230	276	319	5
16				163	213	264	319	369	
Basis	36	36	32	35	44	39	68	9	299

Stump height, 1 foot; top diameter inside of bark, 5 inches; trees scaled in 16-foot lengths.

Compiled by the Frustum Form Factor method from data collected by E. E. Probstfield. A. F. Verrall assisted in the computations.

Difference between total volume of trees used as a basis and the interpolated volumes taken from table, 0.13 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±5.33 per cent.

Block indicates extent of original data.

Preliminary Table.

Table 11

SECOND-GROWTH ASPEN

(Populus tremuloides)

Minnesota

Gevorkiantz, S. R. **1926** Scribner Decimal C

Diameter breast high	Number of 16-foot logs								Basis
	1	1½	2	2½	3	3½	4	4½	
	Volume—board feet, in tens								
Inches									*Trees*
7	2	3	4	6					20
8	2	3	4	6	7				47
9	2	3	5	6	8	9			37
10		3	5	7	8	10	12		36
11		4	6	7	9	11	13	15	22
12		4	6	8	10	13	15	17	26
13			7	9	12	14	17	20	23
14			8	11	14	16	19	23	18
15				12	15	19	22	26	5
16				14	17	22	26	30	
Basis	22	34	27	45	25	45	35	1	234

Stump height, 1 foot; top diameter inside of bark, 6 inches. Scaled in 16-foot logs. Compiled by the Frustum Form Factor method from data collected in 1925 by E. E. Probstfield. A. F. Verrall assisted in the computations.

Difference between total volume of trees used as a basis and the interpolated volumes taken from the table, 0.35 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±6.48 per cent.

Block indicates the extent of the original data.

Preliminary Table.

Table 12

SECOND-GROWTH ASPEN

(*Populus tremuloides*)

Minnesota

Gevorkiantz, S. R. **1926** Cords

Diameter breast high	Total height of tree—feet													Basis	
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
	Volume—cords														
Inches															*Trees*
4	.01	.01	.02	.02	.02	.03	.03	.04							84
5	.02	.03	.03	.04	.04	.05	.05	.06	.06						74
6	.03	.04	.05	.06	.06	.07	.07	.08	.09	.10					61
7			.06	.07	.08	.09	.10	.11	.12	.13	.14				42
8			.08	.09	.10	.11	.12	.13	.14	.16	.17	.18			47
9					.12	.13	.15	.16	.17	.19	.20	.21			38
10					.14	.16	.17	.19	.20	.22	.23	.25	.26		36
11						.18	.20	.22	.23	.25	.27	.29	.31		24
12							.23	.25	.27	.29	.31	.33	.35		27
13								.28	.30	.32	.35	.37	.39	.41	21
14									.34	.36	.38	.41	.43	.46	18
15									.37	.40	.43	.46	.48	.51	5
16									.42	.44	.48	.51	.54	.57	
Basis		4	25	57	63	43	44	43	33	38	47	57	23	1	477

Standard cords, 4x4x8 feet.

Volume of peeled stem above a one-foot stump to a top diameter inside of bark of 3 inches.

Compiled from the merchantable volume in cubic feet by dividing the volume per tree by the number of cubic feet per cord for each D. B. H. class.

Data collected in 1925 by E. E. Probstfield.

Block indicates extent of original data.

Table 13

SECOND-GROWTH ASPEN

(*Populus tremuloides*)

Minnesota

Gevorkiantz, S. R. — 1926 — Cubic feet

Diameter breast high	Total height of tree—feet															
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	Basis
	Total volume—cubic feet															
Inches																*Trees*
2	.26	.31	.37	.42												31
3	.57	.69	.80	.92	1.0	1.1	1 3									74
4	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2 6							84
5	1.6	1.9	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3						74
6		2.7	3.1	3.5	4.0	4.4	4.9	5.3	5.8	6.2	6.6					61
7				4.8	5.4	6.0	6.6	7.2	7.8	8.3	8.9	9.5	10.1			42
8				6.2	7.0	7.7	8.5	9.3	10.0	10.8	11 6	12.4	13.1			47
9						9.7	10.7	11.6	12.6	13.6	14.5	15.5	16.5			38
10						11.9	13.1	14.3	15.4	16.6	17.8	19.0	20.2	21.4		36
11							15 7	17.1	18.6	20.0	21.4	22.9	24.3	25.7		24
12								20.2	21.9	23.6	25.3	27.0	28.7	30.4		27
13									25.6	27.6	29.6	31.6	33.5	35.5	37.5	23
14										31.9	34.1	36.4	38.7	41.0	43.3	18
15										36.4	39.0	41.6	44.2	46.8	49.4	5
16										41	44	47	50	53	56	
Basis	9	20	47	52	63	63	43	44	43	33	38	47	57	24	1	584

Volume includes stump, stem, and top without bark.

Compiled by the form factor method from data collected by E. E. Probstfield in 1925.

Cubed in 8-foot sections by Smalian's formula. A. F. Verrall assisted in the computations.

Block indicates the extent of the original data.

Difference between total volume of trees used as a basis and volume as taken from the table, 0.08 per cent.

Average deviation of individual tree volumes from interpolated tabular volumes, ±5.33 per cent.

Table 14

SECOND-GROWTH ASPEN

(*Populus tremuloides*)

Minnesota

Gevorkiantz, S. R. **1926** Merchantable cubic feet

Diameter breast high	Total height of tree—feet														Basis
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	
	Merchantable volume—cubic feet														
Inches															*Trees*
4	.58	.76	.93	1.1	1.3	1.5	1.6	1.9							84
5	1.3	1.5	1.8	2.2	2.5	2.8	3.1	3.4	3.7						74
6	2.2	2.5	2.9	3.4	3.8	4.2	4.7	5.2	5.6	6.1					61
7			4.2	4.8	5.4	5.9	6.5	7.2	7.8	8.4	8.9	9.5			42
8			5.6	6.3	7.0	7.8	8.6	9.4	10.2	11.0	11.7	12.5			47
9					8.9	9.9	10.8	11.8	12.8	13.8	14.8	15.8			38
10					11.0	12.2	13.4	14.6	15.8	17.0	18.2	19.4	20.6		36
11						14.7	16.2	17.6	19.1	20.5	22.0	23.4	24.9		24
12							19.2	20.9	22.6	24.4	26.1	27.7	29.5		27
13								24.5	26.5	28.5	30.5	32.4	34.4	36.4	21
14									30.7	33.0	35.2	37.5	39.8	42.1	18
15									35.1	37.7	40.2	42.8	45.4	48.0	5
16									40	43	46	49	52	55	
Basis		4	25	57	63	43	44	43	33	38	47	57	23	1	477

Volume inside of bark.
Stump height, 1 foot; top diameter inside of bark, 3 inches.
Compiled by expressing merchantable volume as a percentage of the total volume.
Data collected in 1925 by E. E. Probstfield. A. F. Verrall assisted in the computations.
Difference between total volume of trees used as a basis and the volumes as taken from the table, 0.16 per cent.
Average deviation of individual tree volumes from interpolated tabular volumes, ±6.05 per cent.
Block indicates extent of original data.

Table 15

BALSAM FIR

(*Abies balsamea*)

Maine

Zon **1914** Scribner

Diameter breast high	Swamp					Hardwood slope and flat					
	Total height of tree—feet				Diameter inside bark of top	Total height of tree—feet					Diameter inside bark of top
	40	50	60	70		40	50	60	70	80	
	Volume—board feet					Volume—board feet					
Inches					*Inches*						*Inches*
7	14	17	20	22	5.8	13	19	27			5.8
8	19	23	27	32	5.9	21	26	33	40		5.9
9	24	31	37	44	6.1	29	34	41	48	56	6.0
10		39	48	57	6.2	38	45	52	60	70	6.1
11		48	60	73	6.4		56	65	75	86	6.2
12		57	73	92	6.6		69	80	92	107	6.3
13		66	87	110	6.8		82	95	111	130	6.4
14								111	132	155	6.4
15								127	153	182	6.5
16								144	174	209	6.6

Based upon analysis of 1,056 trees. Stump height, 1 foot.
Table 41, U. S. Dept. of Agr. Bul. 55, Balsam Fir. 1914.

Table 16

BALSAM FIR

(*Abies balsamea*)

Ontanagon County, Michigan

Brotherton — **1910** — Scribner

Diameter breast high	Number of 16-foot logs			
	1	2	3	4
	Volume—board feet			
Inches				
10	30	50	95	
12	55	75	100	
14	80	135	165	
16	95	190	200	
18	140	240	300	335
20	185	325	405	475
22	240	400	500	550

Top diameter inside of bark, 8 inches.
Basis: approximately 100 trees for each D. B. H. class.
Data collected south of Bruce Crossing in 1902.

Table 17

BALSAM FIR

(Abies balsamea)

Maine, New York, New Hampshire

Zon	1914							Cords
Diameter breast high	Total height of tree—feet							Basis
	20	30	40	50	60	70	80	
	Total volume—cords							
Inches								*Trees*
3	.005	.008						26
4	.009	.016	.022					45
5	.016	.024	.033	.042				61
6		.034	.045	.057	.068			92
7		.045	.060	.075	.089	.105		314
8			.078	.096	.114	.137	.168	551
9			.099	.119	.142	.171	.203	399
10			.121	.146	.173	.204	.240	275
11			.146	.178	.206	.241	.278	199
12				.213	.244	.281	.320	120
13					.284	.324	.368	70
14						.366	.419	19
Total								2,171

Table 33, U. S. Dept. of Agr. Bul. 55, Balsam Fir. 1914.

Table 18

BALSAM FIR

(Abies balsamea)

New York

Zon 1914 Cubic feet

Diameter breast high	Total height of tree—feet							Basis
	20	30	40	50	60	70	80	
	Total volume—cubic feet							
Inches								*Trees*
3	0.54	0.81						28
4	0.96	1.43	1.91					45
5	1.48	2.21	2.95	3.60				61
6		3.15	4.19	5.23	6.24	7.24		122
7		4.24	5.63	7.01	8.37	9.72	11.07	326
8			7.25	9.01	10.76	12.51	14.24	566
9				11.19	13.38	15.55	17.71	411
10				13.59	16.23	18.86	21.47	275
11				16.10	19.25	22.36	25.50	217
12					22.38	26.06	29.72	119
13					25.71	29.94	34.14	76
14					29.12	33.98	38.74	16
15					32.77	38.14	43.59	0
16					36.53	42.52	48.59	0
Basis	23	64	156	503	836	500	91	2173

Table 19, U. S. Dept. of Agr. Bul. 55, Balsam Fir. 1914.

Table 19

BALSAM FIR

(*Abies balsamea*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R. **1920** Cubic feet

Diameter breast high	Total height of tree—feet				Basis
	40	50	60	70	
	Total volume—cubic feet				
Inches					*Trees*
5	2.6	2.9			13
6	3.9	4.8			73
7	5.4	6.7	7.3		121
8		8.8	9.6	10.6	125
9		10.9	11.9	13.1	101
10		13.2	14.4	15.8	93
11		15.8	17.2	18.8	50
12		18.5	20.1	21.9	17
13				25.1	2
14				28.9	5
Basis					600

Data collected in Agawa River Valley, Twp. 27, R. 20.
Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving averages on height and D. B. H.

Table 20

BALSAM FIR

(*Abies balsamea*)

New York

Zon **1914** Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Merchantable volume—cubic feet					
Inches						*Trees*
6	3.5	4.0				19
7	4.5	5.1	5.9			115
8	5.9	6.8	8.0	9.1		274
9	7.6	8.9	10.4	11.9		209
10		11.2	13.0	14.8	16.6	133
11		13.6	15.6	17.6	19.8	91
12			18.3	20.9	23.6	57
13			21.1	24.5	27.7	31
14				28.4	32.2	7
15				32.9	37.5	7
16				37.8	43.2	4
Total						947

Volume without bark.
Average top diameter, inside bark, 4 inches.
Table 30, U. S. Dept. of Agr. Bul. 55, Balsam Fir. 1914.

Table 21

BALSAM FIR

(Abies balsamea)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R. **1920** Cubic feet

Diameter breast high	Total height of tree—feet				Basis
	40	50	60	70	
	Used volume—cubic feet				
Inches					*Trees*
5	1.5	1.9			13
6	2.5	2.9	3.5		73
7	3.5	4.2	5.0	6.0	121
8	4.8	5.7	6.7	8.0	125
9		7.2	8.7	10.2	101
10		8.9	10.8	12.7	93
11			13.1	15.3	50
12			15.5	18.1	17
13				21.0	2
14				24.1	5
Basis					600

Data collected in Agawa River Valley, Twp. 27, R. 20.
Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving averages on height and D. B. H.

Table 22

BASSWOOD

(*Tilia glabra*)

Michigan, Wisconsin

Frothingham
Barrows

1913

Scribner Decimal C

Diameter breast high	Number of 16-foot logs						Diameter inside bark of top	Basis
	2	2½	3	3½	4	4½		
	Volume—board feet, in tens							
Inches							*Inches*	*Trees*
8	3	5	6				6	6
9	4	5	7				6	9
10	4	6	8	10	13		6	7
11	5	7	9	11	14		6	8
12	6	8	10	13	16		7	7
13	8	9	12	15	18	22	7	9
14	9	11	14	17	20	24	7	7
15	10	13	16	19	23	27	8	17
16	12	15	18	22	26	30	8	17
17		17	21	25	29	34	9	20
18		19	24	28	33	38	9	18
19		21	27	32	37	43	10	14
20		24	30	36	42	48	10	31
21		27	34	40	47	54	11	21
22		30	38	45	52	60	12	14
23		34	42	50	58	67	12	17
24		38	47	56	65	75	13	19
25		41	52	62	72	83	14	14
26		45	57	68	79	92	15	17
27		50	62	75	87	101	15	8
28		54	68	82	96	110	16	9
29		59	74	89	104	119	17	6
30		64	80	97	113	129	17	4
31		69	87	105	122	140	18	8
32		75	94	113	131	150	18	3
33		81	101	121	141	161	19	3
34		87	108	129	150	172	20	4
35		94	115	138	160	183	20	1
36		101	124	147	170	195	21	
37		108	132	156	180	206	22	1
38		115	141	165	190	218	22	
39		122	149	175	200	230	23	
40		130	157	185	210	242	24	
Total								319

Charlevoix and Kalkaska Counties, Mich., Iron and Price Counties, Wis.
Height of stump, 1 foot. Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs where necessary. Average utilization.
Table 38, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. E. H. Frothingham. 1915

Table 23

BASSWOOD

(Tilia glabra)

Michigan, Wisconsin

Frothingham
Barrows **1913** Cords

Diameter breast high	Total height of tree—feet									Basis
	40	50	60	70	80	90	100	110	120	
	Volume—cords									
Inches										*Trees*
8	.08	.10	.12	.14	.15					6
9	.11	.14	.17	.20	.22					9
10	.14	.18	.22	.25	.28	.30				7
11		.22	.26	.31	.34	.37				8
12		.26	.32	.37	.41	.45	.48			7
13			.38	.45	.49	.54	.57			9
14			.45	.52	.58	.63	.67	.70		7
15			.53	.61	.68	.73	.78	.82		17
16			.61	.70	.78	.83	.89	.94	.98	17
17					.88	.94	1.00	1.06	1.12	20
18					.99	1.06	1.13	1.19	1.25	18
19					1.10	1.18	1.26	1.33	1.40	14
20					1.23	1.30	1.39	1.47	1.55	31
21					1.36	1.44	1.52	1.62	1.70	21
22					1.49	1.58	1.67	1.77	1.86	14
23					1.64	1.73	1.83	1.93	2.03	17
24					1.80	1.89	1.99	2.10	2.21	19
25					1.95	2.05	2.15	2.27	2.40	14
26					2.10	2.21	2.32	2.44	2.58	17
27					2.28	2.39	2.50	2.64	2.78	8
28					2.46	2.58	2.70	2.84	3.00	9
29					2.66	2.80	2.96	3.08	3.24	6
30					2.87	3.01	3.14	3.31	3.48	4
31						3.24	3.38	3.55	3.74	8
32						3.49	3.66	3.84	4.04	3
33						3.78	3.94	4.14	4.35	3
34						4.04	4.22	4.43	4.66	4
35						4.32	4.53	4.74	4.98	1
36							4.85	5.09	5.33	
37							5.14	5.39	5.65	1
38							5.46	5.73	6.00	
39							5.78	6.07	6.34	
40							6.10	6.40	6.68	
Total										319

Charlevoix and Kalkaska Counties, Mich.; Iron and Price Counties, Wis.

Compiled from Table 24. Volume includes stem wood, bark, and branch wood. Minimum branch wood taken, 5 feet long, 4 inches in diameter outside of bark at mid point.

Table 76, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 24

BASSWOOD

(Tilia glabra)

Michigan, Wisconsin

Frothingham
Barrows

1912

Cubic feet

Diameter breast high	Total height of tree—feet									Volume of top-wood	Diameter inside bark of top	Per cent of bark	Basis tr[illegible]	
	40	50	60	70	80	90	100	110	120				Logs	Tops
	Volume of logs including bark—cubic feet													
Inches										*Cu.ft.*	*In.*			
8	3.9	5.4	7.0	8	9					2.2	6	22.1	6	6
9	5.7	8.1	10.3	12	14					2.4	6	21.7	9	7
10	7.8	10.7	13.5	16	18	20				2.6	6	21.2	7	6
11		13.5	17.1	20	23	25				2.8	6	20.8	8	7
12		16.6	21.0	25	28	30	33			3.2	7	20.5	7	5
13			25.0	30	33	36	39			3.7	7	20.1	9	10
14			30.0	35	39	43	46	49		4.3	7	19.7	7	6
15			34.0	41	46	49	53	56		5.2	8	19.4	17	16
16			40.0	47	52	56	60	64	68	6.2	8	19.1	17	15
17					58	63	68	72	76	7.5	9	18.8	20	18
18					65	70	75	80	85	9.0	9	18.6	18	13
19					72	78	83	89	94	10.9	10	18.3	14	15
20					79	85	91	97	103	13.1	10	18.0	31	28
21					86	92	99	106	112	15.6	11	17.8	21	20
22					93	100	107	114	121	18.6	12	17.5	14	12
23					101	108	115	122	131	22.0	12	17.3	17	17
24					109	116	123	131	140	26.0	13	17.1	19	17
25					116	124	132	140	150	30.0	14	16.9	14	12
26					124	132	140	149	159	34.0	15	16.7	17	15
27					132	140	149	159	169	39.0	15	16.5	8	10
28					140	149	158	168	180	45.0	16	16.3	9	9
29					148	158	170	179	191	52.0	17	16.1	6	6
30					156	167	177	189	202	59.0	17	15.9	4	4
31						176	187	199	214	67.0	18	15.7	8	8
32						185	197	211	226	77.0	18	15.5	3	1
33						195	208	222	238	88.0	19	15.4	3	3
34						205	219	234	251	98.0	20	15.2	4	4
35						215	230	247	265	109.0	20	15.1	1	1
36							242	260	279	121.0	21	14.9		
37							255	274	293	131.0	22	14.7	1	
38							268	288	308	142.0	22	14.6		
39							280	302	323	153.0	23	14.4		
40							294	317	338	163.0	24	14.3		
Total													319	291

Charlevoix and Kalkaska Counties, Mich., Iron and Price Counties, Wis.

The "log" volume is the solid contents of wood and bark between a stump height of one foot and the "diameter inside bark of top" shown in the twelfth column. The volume of "top" is that contained in the stem above this point, and in addition all branches suitable for cordwood having a diameter, outside bark, of 4 inches or more at the middle of a 5-foot stick.

Table 36, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. E. H. Frothingham. 1915.

Table 25

BEECH

(*Fagus grandifolia*)

Michigan

Frothingham
Barrows — **1912** — Scribner Decimal C

Diameter breast high	Number of 16-foot logs								Diameter inside bark of top	Basis
	1	1½	2	2½	3	3½	4	4½		
	Volume—board feet, in tens									
Inches									*Inches*	*Trees*
6	1.6	2.5	3	4	5				6	2
7	1.7	2.7	3	4	6				6	13
8	1.8	2.9	4	5	7	8			6	20
9	2.0	3.2	4	6	8	10			6	11
10	2.2	3.7	5	7	9	11	13		6	23
11	2.4	4.2	6	8	11	13	16		6	22
12	2.6	4.7	7	9	12	15	18	21	7	30
13	2.8	5.3	8	11	14	18	21	24	7	19
14	3.0	6.0	9	12	16	20	24	28	7	25
15	3.3	6.8	11	14	18	23	27	31	8	26
16	3.6	7.7	12	16	21	25	30	35	8	28
17		8.5	14	19	24	29	34	40	9	14
18		9.5	16	21	27	32	39	45	9	14
19		11.0	18	24	31	37	43	50	10	9
20			20	28	35	42	49	56	10	6
21			22	32	39	47	55	63	11	7
22			25	36	44	53	62	71	12	8
23				40	50	60	69	80	12	4
24				44	56	67	78	89	13	3
25					62	74	86	100	14	1
26					68	82	96	111	15	
Total										285

Wexford County.
Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs. Stump height, 1 foot. Average utilization.
Table 20, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. E. H. Frothingham. 1915.

Table 26

BEECH

(*Fagus grandifolia*)

Michigan

Frothingham
Barrows **1912** **Cords**

Diameter breast high	Total height of tree—feet							Basis
	Volume—cords							
Inches								*Trees*
6	.027	.035	.044	.057				2
7	.056	.068	.088	.112				14
8	.085	.103	.128	.161	.176	.207		20
9	.117	.137	.165	.201	.228	.267		11
10	.151	.173	.205	.247	.284	.329	.380	23
11	.187	.213	.244	.297	.345	.399	.455	22
12	.224	.256	.287	.352	.412	.473	.535	30
13		.300	.329	.411	.485	.555	.624	19
14		.340	.376	.475	.564	.644	.721	25
15		.385	.423	.543	.649	.740	.824	26
16		.417	.472	.613	.739	.845	.940	28
17			.524	.691	.833	.957	1.060	14
18			.576	.771	.939	1.072	1.188	14
19				.860	1.048	1.197	1.323	9
20				.957	1.167	1.331	1.472	6
21				1.075	1.296	1.480	1.629	7
22				1.197	1.444	1.632	1.795	8
23				1.321	1.600	1.799	1.968	4
24						1.969	2.161	3
25						2.149	2.349	1
26						2.333	2.547	
Total								286

Wexford County.

Compiled from Table 27. Converting factor, 75 cubic feet per cord. Volume includes wood, bark, and branch wood above a 1-foot stump. Minimum branch wood taken, 5-foot stick, 2 inches outside of bark at middle.

Table 37, U. S. Dept. of Agr. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 27

BEECH

(*Fagus grandifolia*)

Michigan

Frothingham
Barrows **1912** **Cubic feet**

Diameter breast high	Total height of tree—feet: 40		50		60		70		80		90		100		Diameter, inside bark at top	Per cent of bark	Basis, trees	
	Volume including bark—cubic feet																	
	Logs	Top	Logs	Top	Logs	Top	Logs	Top	Logs	Top	Logs	Top	Logs	Top			Logs	Tops
Inches															*In.*			
4		0.7		0.9											6	8.1		3
5		0.9		1.1		1.4									6	8.0		3
6	1.0	1.0	1.3	1.3	1.7	1.6	2.4	1.9							6	7.9	2	5
7	2.9	1.3	3.5	1.6	4.7	1.9	6.2	2.2							6	7.8	14	16
8	4.9	1.5	5.9	1.8	7.4	2.2	9.6	2.5	10.4	2.8	12.4	3.1			6	7.7	20	15
9	7.1	1.7	8.2	2.1	10.0	2.4	12.3	2.8	13.9	3.2	16.5	3.5			6	7.6	11	15
10	9.4	1.9	10.7	2.3	12.7	2.7	15.4	3.1	17.8	3.5	21.0	3.9	24	4.3	6	7.6	23	23
11	11.8	2.2	13.4	2.6	15.3	3.0	18.8	3.5	22.0	3.9	26.0	4.3	29	4.7	6	7.5	22	29
12	14.4	2.4	16.3	2.9	18.1	3.4	23.0	3.8	27.0	4.3	31.0	4.8	35	5.2	7	7.4	30	25
13			19.3	3.2	21.0	3.7	27.0	4.2	32.0	4.8	36.0	5.3	41	5.8	7	7.3	19	18
14			22.0	3.5	24.0	4.1	31.0	4.7	37.0	5.3	42.0	5.9	48	6.5	7	7.2	25	25
15			25.0	3.9	27.0	4.5	35.0	5.2	43.0	5.9	49.0	6.6	54	7.3	8	7.1	26	23
16			27.0	4.3	30.0	4.9	40.0	5.6	49.0	6.5	56.0	7.5	62	8.5	8	7.0	28	21
17					34.0	5.4	45.0	6.3	55.0	7.3	63.0	8.5	70	9.7	9	6.9	14	14
18					37.0	5.9	51.0	7.0	62.0	8.3	71.0	9.6	78	11.0	9	6.8	14	10
19							56.0	8.1	69.0	9.6	79.0	11.1	87	12.6	10	6.7	9	6
20							62.0	9.5	76.0	11.2	87.0	13.0	96	14.8	10	6.6	6	5
21							69.0	11.6	84.0	13.5	96.0	15.4	105	17.3	11	6.5	7	8
22							75.0	14.8	92.0	16.6	104.0	18.3	115	20.0	12	6.4	8	4
23							81.0	18.1	100.0	20.0	113.0	21.7	125	23.0	12	6.3	4	1
24											123.0	25.0	135	27.0	13	6.2	3	
25											132.0	29.0	145	31.0	14	6.1	1	
26											142.0	33.0	156	35.0	15	6.0		
Total																	286	239

Wexford County.

The "log" volume is the solid contents of wood and bark between a stump height of 1 foot and the "diameter inside bark of top" shown in the fourth from the last column. Volume of "top" is contained in the stem above this point, and in addition all branches suitable for cordwood, having a diameter, outside bark, of 2 inches or more at the middle of a 5-foot stick. The entire volume of trees too small to yield a 6-inch log is considered topwood.

Table 32, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. E. H. Frothingham. 1915.

Table 28

PAPER BIRCH

(Betula papyrifera)

Ontanagon County, Michigan

Brotherton **1910** Cords

Diameter breast high	Merchantable length—feet				
	10	20	30	40	50
	Volume—cords				
Inches					
6	.02	.04	.05	.07	.08
7	.03	.05	.07	.08	.10
8	.04	.07	.09	.11	.13
9	.05	.08	.11	.13	.16
10	.06	.10	.13	.16	.19
11	.07	.12	.16	.19	.22
12	.08	.14	.19	.22	.26
13		.17	.22	.26	.30
14		.19	.25	.30	.34
15		.22	.29	.34	.38

Volume to 4 inches, including limbs and bark.
Volume obtained from measurements on stacked cords 4x4x8 feet.
Data collected South of Bruce Crossing, 1902.

Table 29

PAPER BIRCH

(*Betula papyrifera*)

Maine and New Hampshire

Dana, S. T. 1909 Cubic feet

Diameter breast high	Total height of tree—feet				
	50	60	70	80	90
	Total volume—cubic feet				
Inches					
4	2.5	3.0			
5	3.7	4.3	4.8		
6	5.2	5.9	6.7	7.8	
7	6.8	7.8	9.0	10.4	12.2
8	8.9	10.2	11.5	13.3	15.3
9	11.2	12.8	14.5	16.5	18.8
10	14.0	15.9	18.0	20.4	22.8
11	17.2	19.5	21.8	24.6	27.5
12	20.0	23.4	26.3	29.5	33.0
13		28.0	31.5	35.3	39.6
14		33.0	37.3	42.1	47.4
15		38.9	44.0	49.7	55.8
16			51.0	57.5	60.0

Volume includes bark.
Table 3, U. S. F. S. Circ. 163. Paper Birch in the Northeast. S. T. Dana. 1909.

Table 30

PAPER BIRCH

(*Betula papyrifera*)

Maine and New Hampshire

R. M. Brown — **1921** — Cubic feet

Diameter breast high	Number of 16-foot logs									Basis
	½	1	1½	2	2½	3	3½	4	4½	
	Merchantable volume—cubic feet									
Inches										*Trees*
4	1	1	2	2	3					9
5	1	2	2	3	4	4				
6	2	3	3	4	5	6	7			48
7		3	4	5	7	8	9			76
8		4	6	7	8	10	11	13	15	70
9			7	8	10	12	14	16	18	68
10			8	10	12	14	17	19	22	85
11				12	14	17	20	23	26	73
12				13	16	20	23	26	31	35
13					19	22	26	31	35	32
14					22	26	30	35	40	22
15						29	34	39	45	7
16						32	38	44	50	12
17						36	42	48	56	2
18						39	46	54	62	1
19							50	59	68	
20							55	64	75	1
Total	1	10	17	35	102	146	165	79	6	561
	Deviation, per cent									Average
Average of individual trees from tabular values		±23.6	±8.4	±10.8	±8.6	±7.4	±7.0	±7.1	±10.1	±8.0
Aggregate for height class		−19.9	−.2	−2.5	−2.1	−1.6	+1.3	+3.2	+7.3	+ .8

Stump height for trees 12 inches in diameter breast high and over equals 1 foot; below 12 inches diameter breast high, stump height equals diameter. Top diameter 3 inches. Cubed in 10-foot sections excepting butt log. Smalian formula. Data collected by S. T. Dana, 1907, and on Maine Forest Survey 1902-3. Values outside of observed data obtained by extending straight lines on logarithmic cross-section paper. Seedlings and sprouts combined after comparison of form quotients. Block indicates extent of observed data.

Table 17, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 31

YELLOW BIRCH

(*Betula lutea*)

Michigan, Wisconsin

Frothingham Barrows **1912** **Scribner Decimal C**

Diameter breast high	Number of 16-foot logs					Diameter inside bark of top	Basis
	1½	2	2½	3	3½		
	Volume—board feet, in tens						
Inches						*Inches*	*Trees*
8	2.3	3.7				6	11
9	3.0	4.5				6	17
10	3.6	5.4	7.2	9.2		6	26
11	4.3	6.3	8.4	10.		6	17
12	5.0	7.3	9.7	12.		7	27
13	5.7	8.3	11.	14.	17.	7	20
14	6.5	9.4	13.	16.	19.	7	16
15	7.3	11.	14.	18.	21.	8	8
16	8.2	12.	16.	20.	24.	8	16
17		14.	18.	23.	27.	9	15
18		16.	21.	26.	30.	9	15
19		18.	23.	29.	34.	10	13
20		20.	27.	33.	38.	10	9
21		23.	30.	37.	43.	11	6
22		26.	34.	41.	49.	12	3
23		29.	38.	46.	55.	12	5
24		33.	43.	51.	61.	13	4
25		36.	47.	57.	68.	14	4
26		40.	52.	63.	75.	15	2
27		44.	57.	69.	83.	15	
28		48.	62.	76.	90.	16	1
29		52.	67.	83.	98.	17	2
30		56.	72.	90.	105.	17	
Basis							237

Gogebic and Wexford Counties, Mich.; Marinette and Vilas Counties, Wis.

Scaled from taper curves; mostly in 16.3-foot logs, with a few shorter logs where necessary. Stump height, 1 foot. Average utilization.

Table 15, U. S. Dept. of Agr. Bul. 285. The Northern Hardwood Forest. E. H. Frothingham. 1915.

Table 32

YELLOW BIRCH

(*Betula lutea*)

Michigan, Wisconsin

Frothingham
Barrows

1912

Cords

Diameter breast high	Total height of tree—feet					Basis
	50	60	70	80	90	
	Volume—cords					
Inches						*Trees*
6	.035	.039	.043			4
7	.085	.091	.099	.103		12
8	.128	.136	.148	.157	.169	11
9	.164	.175	.193	.209	.229	17
10	.204	.219	.244	.267	.292	26
11	.249	.267	.301	.331	.363	17
12	.296	.323	.364	.400	.439	27
13	.347	.384	.433	.476	.520	20
14	.399	.451	.512	.561	.609	16
15		.528	.599	.653	.703	8
16		.613	.692	.751	.800	16
17		.711	.791	.853	.908	15
18		.815	.896	.961	1.019	15
19		.925	1.004	1.075	1.136	13
20		1.041	1.117	1.189	1.257	9
21			1.231	1.309	1.387	6
22			1.351	1.439	1.523	3
23			1.473	1.571	1.664	5
24			1.603	1.711	1.815	4
25			1.748	1.871	1.987	4
26			1.883	2.016	2.144	2
27			2.031	2.176	2.317	
28			2.181	2.340	2.488	1
29			2.333	2.504	2.661	2
30			2.487	2.667	2.837	
Total						253

Gogebic and Wexford Counties, Mich.; Marinette and Vilas Counties, Wis.
Compiled from Table 33 by a converting factor of 75 cubic feet to the cord.
Table 23, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 33

YELLOW BIRCH

(*Betula lutea*)

Michigan, Wisconsin

Frothingham
Barrows **1912** Cubic feet

Diameter breast high	Total height of tree—feet						Diameter inside bark of top	Basis trees	
	40	50	60	70	80	90		Logs	Tops
	Volume including bark—cubic feet								
Inches							*Inches*		
4	0.8	0.9							
5	1.1	1.3	1.4						6
6	1.4	2.6	2.9	3.2				4	4
7	1.7	6.4	6.8	7.4	7.7			12	12
8	1.9	9.6	10.2	11.1	11.8	12.7	6	11	11
9		12.3	13.1	14.5	15.7	17.2	6	17	17
10		15.3	16.4	18.3	20.0	22.0	6	26	26
11		19	20	23	25	28	6	17	17
12		22	24	27	30	33	7	27	27
13		26	29	33	36	39	7	20	20
14		30	34	38	42	46	7	16	17
15			40	45	49	53	8	8	8
16			46	51	56	60	8	16	14
17			54	59	64	68	9	15	15
18			61	68	72	76	9	15	15
19			69	75	80	85	10	13	12
20			78	84	89	94	10	9	7
21				92	98	104	11	6	5
22				102	108	115	12	3	2
23				110	118	125	12	5	5
24				120	128	136	13	4	4
25				131	140	149	14	4	4
26				141	151	161	15	2	2
27				152	163	174	15		
28				164	175	187	16	1	1
29				175	188	200	17	2	2
30				186	200	213	17		
Total								253	253

Gogebic and Wexford Counties, Mich.; Marinette and Vilas Counties, Wis.

Height includes both logs and top. The "log" volume is the solid contents of wood and bark between a stump height of 1 foot and the "diameter inside bark of top" shown in the eighth column. The volume of "top" is that contained in the stem above this point and in addition all branches suitable for cordwood having a diameter, outside bark, of 2 inches or more at the middle of a 5-foot stick. The entire volume of trees too small to yield a 6-inch log is considered topwood. Bark comprises about 13 per cent of total volume.

Table 31, U. S. Dept. of Agr. Bul. 285. The Northern Hardwood Forest. E. H. Forthingham. 1915.

Table 34

NORTHERN WHITE CEDAR

(*Thuja occidentalis*)

Ontanagon County, Michigan

Brotherton **1910** Scribner

Diameter breast high	Number of 16-foot logs			
	1	2	3	4
	Volume—board feet			
Inches				
10	20	40		
12	30	50		
14	50	100	120	
16	80	140	170	
18	110	170	220	
20	160	240	320	
22	210	330	410	
24	280	440	530	580

Top diameter inside of bark, 8 inches.
Basis, approximately 100 trees in each D. B. H. class.
Data collected South of Bruce Crossing, 1902.

Table 35

NORTHERN WHITE CEDAR

(Thuja occidentalis)

New York

Belyea **1922** **Cubic feet**

Diameter breast high	Total height of tree—feet						
	20	30	40	50	60	70	80
	Total volume—cubic feet						
Inches							
5	0.51	1.02	1.44	1.90			
6	1.75	2.31	2.79	3.70			
7	2.65	3.42	4.43	5.65			
8	4.17	4.89	6.02	7.50			
9	5.16	6.20	7.54	9.23	10.35		
10		7.92	9.27	11.00	12.90	15.10	
11			11.57	13.31	15.29	17.55	20.05
12			13.91	15.90	18.00	20.27	23.00
13			16.30	18.35	20.45	23.30	26.39
14			18.72	20.85	23.30	25.95	29.70
15			21.45	24 25	26.70	29.65	32.80
16				27.10	29.95	33.30	36.80
17				30.65	33.50	36.65	40.35
18				33.35	36.90	40.60	44.50
19				36.60	40.75	44.55	47.85
20				41.05	44.55	48.25	51.95

Based on 221 trees collected in St. Lawrence Co., N. Y.
Table 65, N. Y. State College of Forestry. Bul. 14, H. C. Belyea, O. M. Porter.

Table 36

NORTHERN WHITE CEDAR

(*Thuja occidentalis*)

New York

Belyea **1922** **Cubic feet**

Diameter breast high	Total height—feet						
	20	30	40	50	60	70	80
	Volume—cubic feet						
Inches							
5	0.40	0.78	1.10	1.45			
6	1.38	1.82	2.20	2.92			
7	2.15	2.78	3.60	4.60			
8	3.50	4.10	5.05	6.30			
9	4.45	5.35	6.50	7.95	9.80		
10		7.00	8.20	9.75	11.40	13.35	
11			10.40	12.00	13.75	15.80	18.10
12			12.65	14.45	16.35	18.40	20.90
13			15.00	16.90	18.80	21.45	24.30
14			17.50	19.50	21.75	24.20	27.80
15			20.25	22.90	25.20	28.00	30.95
16				25.80	28.50	31.75	35.00
17				29.20	31.95	34.95	38.55
18				32.00	35.41	39.15	42.70
19				35.52	39.45	43.25	46.45
20				40.00	43.50	47.00	50.50

Based on 221 trees collected in St. Lawrence Co., N. Y.
Utilization to 4-inch top inside bark and 1-foot stump.
Table 66. N. Y., State College of Forestry, Bul. 14, H. C. Belyea, O. M. Porter.

Table 37

SECOND-GROWTH COTTONWOOD

(Populus deltoides)

Mississippi Valley

Williamson
Homans **1912** Scribner Decimal C

Diameter breast high	Total height of tree—feet										Diameter inside bark of top	Basis
	90	100	110	120	130	140	150	160	170	180		
	Volume—board feet, in tens											
Inches											*Inches*	*Trees*
12	1	2	3	4							11	
13	4	5	6	7							12	
14	6	7	8	9							12	20
15	9	11	12	13							12	
16	12	14	15	17	19						12	30
17	15	18	20	22	24						13	
18	19	22	25	27	30	33					13	32
19	23	26	30	33	37	40					13	
20	26	31	35	39	43	47	51				13	33
21	30	36	40	45	50	55	59				14	
22	34	41	46	52	57	62	66	70			14	32
23	39	46	52	58	64	69	74	78			15	
24	43	51	58	65	71	77	82	86	91		15	34
25		57	64	71	78	84	90	94	98		15	
26		63	71	78	85	92	97	102	106		16	50
27		69	77	85	92	99	105	110	115		16	
28		75	84	92	100	107	113	118	123		17	47
29		81	90	99	108	115	121	127	132		17	
30		87	96	106	115	123	130	135	141	147	18	40
31			102	112	122	131	138	145	150	156	18	
32			108	119	129	139	147	154	160	166	19	28
33			114	126	137	148	156	163	170	176	19	
34			120	133	144	156	165	172	180	186	20	33
35			125	140	152	164	174	182	189	196	20	
36			131	147	159	172	182	191	200	207	21	30
37				153	166	180	191	201	210	218	22	
38				160	173	188	200	211	221	229	22	24
39				167	180	196	208	221	231	240	23	
40				173	187	204	217	231	241	251	24	20
41					194	211	225	240	250	262	25	
42					201	218	234	249	260	273	25	17
43					208	226	242	258	270	284	26	
44					215	233	250	266	280	294	27	5
45					222	241	259	275	290	305	28	
46					229	248	267	284	300	315	28	5
47					236	256	276	293	310	326	29	
48					243	263	284	302	319	336	30	
49					250	270	292	311	329	347	31	
50					256	278	301	320	338	357	32	
Total												480

Height of stump, 2 feet for trees less than 36 inches in diameter breast high; 2.5 feet for trees 36 inches and over. Trees from Arkansas, Missouri, Kentucky, Mississippi, Tennessee, Louisiana.

Table 12, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 38

SECOND-GROWTH COTTONWOOD

(Populus deltoides)

Mississippi Valley

Williamson
Homans

1912

Scribner Decimal C

Diameter breast high	Number of 16-foot logs						Diameter inside bark of top	Basis
	1	2	3	4	5	6		
	Volume—board feet, in tens							
Inches							*Inches*	*Trees*
14	8	17					12	21
15	9	18					12	
16	10	19					12	30
17	11	21					13	
18	12	23	30				13	32
19	14	25	34				13	
20	16	28	38	46			13	33
21	18	31	43	53			14	
22	20	35	48	61	72		14	32
23	23	39	54	68	80		15	
24	26	44	60	75	88		15	34
25		48	66	82	96		15	
26		54	72	89	104	115	16	50
27		59	79	97	113	124	16	
28		64	86	105	121	134	17	47
29		70	93	113	130	144	17	
30		76	100	122	139	156	18	40
31		82	107	130	149	167	18	
32		88	114	140	160	170	19	28
33			121	149	171	192	19	
34			129	158	182	205	20	31
35			136	167	194	219	20	
36			144	177	205	233	21	30
37			152	186	217	247	22	
38			160	195	229	261	22	24
39			168	205	241	275	23	
40			176	215	253	289	24	20
41			184	225	265	303	25	
42			193	235	276	317	25	16
43			201	245	288	331	26	
44			210	255	300	346	27	5
45				266	313	361	28	
46				276	325	376	28	5
47				287	337	392	29	
48				297	350	407	30	
49				307	362	423	31	
50				319	374	439	32	
Total								478

Height of stump, 2 feet for trees less than 36 inches in diameter breast high; 2.5 feet for trees 36 inches and over. Trees from Arkansas, Kentucky, Louisiana, Missouri, Mississippi, Tennessee.

Table 11, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 39

SECOND-GROWTH COTTONWOOD

(Populus deltoides)

Mississippi Valley

Homans
Williamson

1910

Cubic feet

Diameter breast high	Total height of tree—feet											Basis
	50	60	70	80	90	100	110	120	130	140	150	
	Peeled volume—cubic feet											
Inches												*Trees*
5	2.5	3.0	3.5									16
6	3.5	4.5	5.0	6.0								26
7	5.0	6.0	6.5	7.5	8.5							22
8	6.5	7.5	8.5	9.5	11.0	12.5						24
9		9.5	10.5	12.0	14.0	16.5	19.5					29
10		11.5	13.0	15.0	17.5	20.5	24.0					21
11		13.5	15.5	18.0	21.0	24.5	28.5	33.0				32
12		16.0	18.5	21.5	25.0	29.0	33.5	38.0				20
13			22.5	25.5	29.0	33.5	38.0	43.0				25
14			26.5	29.5	33.5	38.0	43.0	48.5	54.0			25
15				33.5	37.5	42.5	48.5	54.5	60.0			18
16				37.5	42.0	47.5	53.5	60.0	67.0			14
17				41.5	47.0	53.0	59.5	66.5	73.5	80.5		19
18					52.0	58.5	65.5	73.0	80.5	89.0		13
19					56.5	64.5	72.5	80.5	89.0	97.5		19
20					62.0	71.0	79.5	88.5	97.5	107.5		9
21						78.5	88.0	97.5	107.5	118.5	129.0	8
22						86.5	97.0	107.5	118.5	130.0	142.5	7
23						95.5	107.0	118.5	130.0	142.5	156.0	6
24							118.5	130.5	142.5	156.0	170.0	9
25							131.0	143.0	156.0	169.0	183.0	9
26								156.0	169.0	183.0	197.0	10
27								168.5	182.0	196.0	211.5	9
28									194.5	210.0	225.5	2
29									208.0	223.5	239.5	10
30									221.5	238.0	254.5	7
Basis	20	36	26	41	54	55	64	35	30	33	15	409

Trees from Arkansas, Kentucky, Tennessee, Missouri, Mississippi, and Louisiana. Table 14, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 40

ELM

(*Ulmus americana*)

Ontanagon County, Michigan

Brotherton — **1910** — Scribner

Diameter breast high	Number of 16-foot logs						
	1	1½	2	2½	3	3½	4
	Volume—board feet						
Inches							
10	30	40	50	75	90		
12	55	80	105	125	140		
14	80	130	145	165	185		
16	115	160	185	220	260	300	330
18	160	205	250	300	350	375	400
20	210	280	360	415	475	510	590
22	250	375	450	525	620	700	750
24	305	475	525	600	710	760	800
26	375	550	625	745	790	920	975
28	460	730	835	880	960	1100	1200
30	550	820	910	1050	1150	1245	1460
32	580	1000	1160	1270	1480	1700	1815
34	655	1100	1340	1500	1640	1675	1705
36	735	1200	1405	1675	1925	2000	2080

Stump height, approximately 2.5 feet; top diameter, 8 inches inside bark. Basis; approximately 100 trees for each D. B. H. class. Data collected South of Bruce Crossing, 1902.

Table 41

MIXED HARDWOODS

Southern Michigan

Chittenden, A. K. **1923**

Diameter breast high	Volume
Inches	*Cubic feet*
2	0.4
3	0.8
4	1.5
5	3.0
6	4.6
7	7.0
8	9.5
9	12.6
10	16.2
11	20.5
12	25.0
13	30.5
14	36.0
15	42.0
16	48.0
17	55.0
18	62.0
19	70.0
20	79.5
21	88.0
22	99.0
23	110.0
24	122.5
25	135.0

Volume includes cordwood in tops and branches.
Table II. Special Bul. 122, Improvement of the Farm Woodlot. Mich. Agr. College.

Table 42

EASTERN HEMLOCK

(Tsuga canadensis)

Michigan, Wisconsin

Frothingham Barrows **1912** **Scribner Decimal C**

Diameter breast high	Total height of tree—feet								Diameter inside bark of top	Basis
	30	40	50	60	70	80	90	100		
	Volume—board feet, in tens									
Inches									*Inches*	*Trees*
8	0.5	0.7	1.3	2.0	2.5	3			6	53
9	0.8	1.4	2.2	2.9	3.5	4			6	72
10	1.2	2.2	3.2	4.0	4.7	5			6	56
11	1.6	2.9	4.2	5.1	6.0	7	8		6	53
12	2.0	3.7	5.3	6.4	7.6	8	9		7	46
13	2.5	4.6	6.5	7.8	9.4	10	11		7	35
14	3.0	5.6	7.7	9.5	11	13	14		7	18
15	3.6	6.5	9	11	13	15	16		8	31
16	4.1	7.6	11	13	16	18	19	20	8	25
17		8.7	12	15	18	21	22	24	8	30
18		10.0	14	18	21	24	26	28	8	14
19			16	20	24	28	30	32	9	16
20			18	23	28	31	34	36	9	20
21			20	26	31	35	38	41	9	11
22			22	29	35	39	43	47	10	13
23				33	38	44	48	52	10	4
24				36	42	49	54	58	10	6
25				39	46	53	60	65	10	9
26				43	51	58	66	72	11	4
27				47	55	64	72	79	11	8
28				50	59	69	78	87	11	6
29				54	64	75	85	94	11	3
30				57	68	80	92	103	12	1
31					72	86	99	111	12	2
32					76	93	107	120	12	1
33					81	99	114	129	12	3
34					85	105	122	138	13	1
35						112	130	148	13	1
36						118	138	157	13	
37							147	167	13	
38							155	178	14	
Total										542

Gogebic County, Mich.; Marinette and Vilas Counties, Wis.

Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs. Stump height 2 feet.

Table 12, U. S. Dept. of Agr. Bul. 152. The Eastern Hemlock. 1913.

Table 43

EASTERN HEMLOCK

(Tsuga canadensis)

Michigan, Wisconsin

Frothingham
Barrows — 1912 — Scribner Decimal C

Diameter breast high	Number of 16-foot logs									Diameter inside bark of top	Basis
	1	1½	2	2½	3	3½	4	4½	5		
	Volume—board feet, in tens										
Inches										*Inches*	*Trees*
8	1.8	2.8	3.8							6	53
9	1.9	3.0	4.2							6	72
10	2.0	3.2	4.7	6						6	56
11	2.3	3.9	5.7	7						6	53
12	2.5	4.5	6.6	8	11					7	46
13	2.6	5.3	7.9	10	13					7	35
14	2.8	6.3	9.2	12	14	17				7	18
15	3.0	7.2	11.0	13	17	20				8	31
16	3.2	8.2	12	15	19	22				8	25
17	3.4	9.4	14	18	21	25				8	30
18	3.6	11.0	16	20	24	28	32			8	14
19	3.8	12.0	18	22	27	31	35			9	16
20	4.0	13.0	20	25	29	34	39			9	20
21		15.0	23	28	33	38	43			9	11
22		17.0	26	31	36	42	48	53		10	13
23			28	34	40	46	53	60		10	4
24			31	37	44	51	58	66		10	6
25			33	40	48	56	64	73		10	9
26			36	43	52	60	70	81	92	11	4
27				47	56	66	77	88	100	11	8
28				50	60	71	83	96	109	11	6
29				53	64	76	90	104	118	11	3
30				56	68	82	96	111	127	12	1
31					72	88	104	120	137	12	2
32					77	93	111	128	146	12	1
33					82	99	118	137	156	12	3
34					87	105	125	145	167	13	1
35						114	134	155	176	13	1
36						121	142	164	187	13	
37						127	150	173	197	13	
38						133	158	183	208	14	
Total											542

Gogebic County, Mich.; Marinette and Vilas Counties, Wis.

Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs where necessary. Stump height, 2 feet.

Table 90, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 44

EASTERN HEMLOCK

(*Tsuga canadensis*)

New York

Belyea **1919** Cords

Diameter breast high	Total height of tree—feet						
	40	50	60	70	80	90	100
	Merchantable volume—cords*						
Inches							
6	.06	.07					
7	.07	.09					
8	.09	.11	.13				
9	.12	.14	.17				
10	.14	.17	.20	.24			
11	.16	.20	.24	.28	.34		
12	.20	.24	.28	.34	.38		
13	.24	.28	.34	.38	.44		
14		.34	.38	.44	.51	.58	
15		.38	.43	.50	.57	.66	
16		.42	.48	.56	.64	.73	.82
17		.46	.56	.62	.71	.80	.90
18		.51	.61	.70	.80	.92	1.04
19			.67	.78	.89	1.04	1.19
20			.73	.85	.99	1.17	1.34
21			.80	.93	1.10	1.29	1.51
22				1.01	1.23	1.44	1.67
23				1.10	1.36	1.60	1.86
24				1.20	1.49	1.77	2.05
25				1.31	1.64	1.95	2.24
26				1.45	1.79	2.16	2.43
27					1.92	2.34	2.62
28					2.00	2.54	2.83
29					2.17	2.74	3.05
30					2.35	2.94	3.27

*Converted on the basis of 90 cubic feet of mixed diameters to the solid cord. Based on 950 trees collected in St. Lawrence Co., N. Y.
Table 51, N. Y. State College of Forestry Bul. 14, H. C. Belyea, O. M. Porter.

Table 45

EASTERN HEMLOCK

(Tsuga canadensis)

Michigan, Wisconsin

Frothingham
Barrows **1912** Cubic feet

Diameter breast high	Total height of tree—feet								Basis
	30	40	50	60	70	80	90	100	
	Unpeeled volume—cubic feet								
Inches									*Trees*
5	1.0	1.2	1.7						18
6	2.0	2.6	3.3						16
7	3.1	4.1	5.2	5.9					28
8	4.1	5.5	7.3	8.4					53
9	5.4	7.4	9.3	10.9	12.3				72
10	7.0	9.5	11.9	14.1	15.7				56
11	8.6	11.8	14.6	17.2	19.6	22			53
12	10.6	14.4	18.0	21.0	24.0	26			46
13	12.5	17.0	21.0	24.0	28.0	31	33		35
14	14.8	20.0	24.0	28.0	33.0	37	39		18
15	17.0	23.0	28.0	33.0	38.0	42	45		31
16	19.3	26.0	32.0	38.0	44.0	48	51	54	25
17			36.0	43.0	50.0	54	59	62	30
18			41.0	48.0	56.0	61	67	71	14
19			45.0	54.0	62.0	69	75	79	16
20			50.0	60.0	69.0	77	83	87	20
21				66.0	76.0	85	91	98	11
22				72.0	83.0	93	100	109	13
23				79.0	91.0	102	109	119	4
24				85.0	99.0	111	119	129	6
25					107.0	120	131	143	9
26					116.0	130	144	156	4
27					123.0	139	155	169	8
28					131.0	147	167	182	6
29						157	179	195	3
30						169	191	208	1
31						180	204	222	2
32						192	218	237	1
33							231	252	3
34							246	267	1
35							260	283	1
36							275	299	
Total									604

Gogebic County, Mich.; Marinette and Vilas Counties, Wis.
Based on taper curves. Volume includes stem with bark between a 2-foot stump and a 4-inch top. Bark forms 19 per cent of the total volume of the stem. Table 17, U. S. Dept. of Agr. Bul. 152, The Eastern Hemlock. 1913.

Table 40

HICKORY

(*Hicoria* sp.)

Mississippi and Ohio Valleys, Appalachians

Boisen 1909 Cubic feet

Diameter breast high	Total height—feet						Used volume
	40	50	60	70	80	90	
	Total volume—cubic feet						
Inches							*Per cent*
5	2.1	3.1	4.3	6.0			40
6	3.3	4.5	5.9	7.8			41
7	4.7	6.2	7.9	9.9	12.6		42
8	6.4	8.2	10.1	12.5	15.5	18.7	44
9	8.2	10.4	12.8	15.5	18.8	22.5	45
10	10.4	13.0	15.8	19.0	22.6	26.7	47
11	12.8	15.9	19.3	23.0	27.0	31.5	49
12	15.6	19.0	23.2	27.4	31.9	36.8	50
13		22.6	27.5	32.1	37.2	42.8	52
14			32.0	37.2	43.0	49.2	53
15			36.8	42.6	49.1	55.8	53
16				48.4	55.5	62.8	54
17				54.5	62.5	70.4	54
18				60.8	69.8	78.8	54

Basis, 365 trees of 5 species cut for staves and bolts. Volume includes tops and larger branchwood.

Table 7, U. S. Forest Service Bul. 80, The Commercial Hickories. 1910.

Table 47

HICKORY

(*Hicoria sp.*)

Mississippi and Ohio Valleys, Appalachians

Boisen 1909 Cubic feet

Diameter breast high	Merchantable length—feet													Diameter inside bark of top	Basis
	5	10	15	20	25	30	35	40	45	50	55	60	65		
	Volume—cubic feet														
Inches														*Inches*	*Trees*
5	1.0	1.8	2.3											4	5
6	1.3	2.5	3.2	3.6										5	19
7	1.6	3.2	4.2	5.0	5.7									6	26
8	2.0	4.0	5.4	6.5	7.5									6	43
9	2.5	4.8	6.6	8.2	9.6	10.0								7	56
10	3.0	5.8	8.1	10.0	11.5	13.0								8	53
11	3.5	6.9	9.7	12.0	14.0	16.0	18.0							8	55
12	4.1	8.0	11.5	14.5	17.0	20.0	21.5	23.5						9	30
13	4.8	9.3	13.5	17.0	20.5	23.5	26.0	28.5	31					10	36
14	5.5	10.5	15.5	20.0	24.0	27.5	31.0	34.0	37					11	36
15	6.2	12.0	17.5	23.0	27.5	32.0	36.0	39.0	43					11	29
16	7.0	14.0	20.0	26.5	31.0	36.0	41.0	45.0	50	54				12	24
17	8.0	15.5	23.0	29.5	36.0	41.0	46.0	51.0	56	61	66			13	23
18		17.5	25.5	33.0	40.0	46.0	52.0	58.0	63	69	74			14	17
19		19.5	28.5	37.0	45.0	52.0	58.0	64.0	70	76	82			14	23
20		21.5	32.0	41.0	50.0	57.0	64.0	71.0	78	84	90	97	103	15	22
21		24.0	35.0	45.0	54.0	63.0	71.0	79.0	86	93	100	107	113	16	19
22		26.0	38.0	50.0	60.0	69.0	77.0	86.0	94	102	110	118	126	16	20
23		28.5	42.0	54.0	65.0	75.0	84.0	93.0	102	111	120	128	137	17	25
24		31.0	45.0	59.0	70.0	81.0	91.0	102.0	111	121	130	139	148	18	16
25		34.0	49.0	64.0	76.0	88.0	99.0	110.0	121	130	140	149	158	19	10
26		36.5	53.0	69.0	82.0	95.0	107.0	119.0	130	140	151	161	171	19	12
27			57.0	74.0	89.0	103.0	116.0	128.0	140	151	162	173	183	20	8
28			61.0	80.0	97.0	112.0	125.0	137.0	149	161	173	185	197	20	3
Basis															610

Data for five species of hickory.
Table 8, U. S. Forest Service Bul. 80, The Commercial Hickories. 1910.

Table 48

RED MAPLE

(*Acer rubrum*)

Massachusetts

E. E. Carter — **1913** — Cords

Diameter breast high	Total height of tree—feet							Basis
	20	30	40	50	60	70	80	
	Merchantable volume—cords							
Inches								*Trees*
3	.009	.011	.015	.018				51
4	.015	.019	.024	.029				36
5		.031	.034	.043	.051			38
6			.048	.060	.072	.081		42
7			.063	.079	.095	.113		25
8			.078	.101	.122	.140	.153	39
9			.095	.125	.149	.168	.184	28
10				.151	.179	.199	.217	20
11				.179	.212	.235	.252	23
12				.210	.251	.276	.294	10
13				.246	.292	.324	.343	9
14				.286	.338	.374	.392	8
15				.332	.390	.430	.450	3
16				.383	.451	.491	.565	4
17							.607	2
Basis								338

[1] A standard cord is a pile 8 feet long by 4 feet high and 4 feet broad. Contractors usually require about 3 inches additional height to allow for settling. Where wood is intended for distillation a length of 50 inches is commonly specified. This influences the converting factor but little, compared with the other variables.

[2] See A Volume Table for Red Maple on the Harvard Forest, by E. E. Carter; Bul. of the Harvard Forestry Club, Vol. II, 1913, pp. 1-8.

Table 49

RED MAPLE

(Acer rubrum)

Massachusetts

E. E. Carter | 1913 | Cubic feet

Diameter breast high	Total height of tree—feet							Basis
	20	30	40	50	60	70	80	
	Merchantable volume, including bark—cubic feet							
Inches								*Trees*
2	0.25	0.35	0.55					59
3	0.60	0.71	1.00	1.2				51
4	1.00	1.30	1.65	2.0				36
5		2.15	2.40	3.0	3.6			38
6			3.45	4.3	5.2	6.2		42
7			4.70	5.9	7.1	8.4		25
8			6.05	7.8	9.4	10.8	11.8	39
9			7.65	10.1	12.0	13.5	14.8	28
10				12.7	15.0	16.7	18.2	20
11				15.6	18.5	20.5	22.0	23
12				18.9	22.5	24.8	26.4	10
13				22.6	26.8	29.7	31.4	9
14				26.8	31.6	35.0	36.7	8
15				31.5	37.0	40.7	42.7	3
16				36.6	43.2	47.0	49.7	4
17							58.4	2
Basis								397

The volumes are for stem and branch wood to a minimum diameter, outside bark, of about 2 inches at the middle of a 4-foot length. The measurements were taken in a wide variety of types, including bottom or swale, pine slope, swamp, and birch and maple coppice. Most of the trees more than 6 inches in diameter breast-high were of seedling origin.

[1]See A Volume Table for Red Maple on the Harvard Forest, by E. E. Carter; Bulletin of the Harvard Forestry Club, Vol. II, 1913, pp. 1-8.

Table 50

SUGAR MAPLE

(Acer saccharum)

Central Michigan

Chittenden, A. K. **1925** Scribner

Diameter breast high	Merchantable length—feet*						Top diameter	Basis
	24	32	40	48	56	64		
	Volume—board feet							
Inches							*Inches*	*Trees*
10	44	60					8.6	19
11	48	68	80				9.1	20
12	53	76	95	112			9.3	32
13	62	87	113	136			9.7	37
14	75	104	132	161	196		10.1	38
15	93	123	156	189	227		10.4	47
16	114	147	184	220	259	293	10.8	48
17	141	174	215	255	294	335	11.2	63
18	171	205	250	295	336	378	11.7	57
19	203	239	288	336	377	424	12.1	36
20		277	329	380	424	473	12.6	30
21		319	372	425	474	527	13.2	46
22		363	418	473	529	586	13.8	50
23		408	467	525	588	650	14.5	36
24		455	519	583	651	722	15.2	44
25		503	574	644	721	804	16.0	28
26		550	634	712	798	899	16.9	25
27			694	787	879	999	17.8	24
28			756	867	967	1108	18.9	13
29			821	951	1061	1220	20.1	10
30				1040	1159	1335	21.3	8
31				1130	1258	1453	22.6	7
32					1357	1571	23.9	9
Basis								725

*Merchantable length is the length which can be used for logs.

Chittenden, A. K., Mich. State College Agr. Exp. Sta. Quart. Bul. Volume of Sugar Maple Trees. Vol. 7. No. 4. 1925.

Table 51

SUGAR MAPLE

(*Acer saccharum*)

Michigan, Wisconsin

Frothingham
Barrows **1912** Scribner Decimal C

Diameter breast high	Number of 16-foot logs						Diameter inside bark of top	Basis
	1½	2	2½	3	3½	4		
	Volume—board feet, in tens							
Inches							*Inches*	*Trees*
8	2.5	3.1	3.8				6	21
9	3.0	4.0	5.0				6	35
10	3.7	4.7	6.2	7.6	9.4		6	23
11	4.3	5.9	7.6	9.3	11		6	26
12	5.0	7.0	9.1	11	14	17	7	25
13	5.7	8.2	11	13	16	19	7	20
14	6.5	9.5	13	16	19	22	7	22
15	7.3	11	15	18	22	25	8	16
16	8.3	12	17	21	25	29	8	22
17	9.3	14	19	24	28	33	9	7
18	10	16	22	27	32	38	9	13
19		18	24	30	37	43	10	6
20		20	27	34	41	49	10	9
21		22	30	38	46	55	11	7
22		25	34	42	52	62	12	7
23		28	37	47	58	69	12	6
24		31	41	52	64	77	13	2
25		34	46	57	71	84	14	6
26		37	50	63	78	93	15	1
27			55	69	86	102	15	2
28			60	76	94	111	16	
29			65	82	102	121	17	
30			69	89	111	130	17	2
Total								278

Gogebic and Wexford Counties, Mich.; Marinette and Vilas Counties, Wis. Scaled from taper curves mostly in 16.3-foot logs, with a few shorter logs where necessary. Stump height, 1 foot. Average utilization.

Table 25, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. 1915.

Table 52

SUGAR MAPLE

(*Acer saccharum*)

Michigan, Wisconsin

Frothingham
Barrows

1912

Cords

Diameter breast high	Total height of tree—feet						Basis
	50	60	70	80	90	100	
	Volume—cords						
Inches							*Trees*
6	.032	.039	.045	.053			9
7	.071	.087	.103	.119			18
8	.113	.132	.151	.169			21
9	.160	.175	.195	.221			35
10	.207	.223	.247	.279	.315		23
11	.257	.273	.304	.343	.387		26
12	.312	.329	.365	.413	.465	.523	25
13		.391	.432	.489	.552	.621	20
14		.456	.505	.572	.644	.727	22
15		.529	.580	.660	.744	.840	16
16		.608	.663	.755	.853	.960	22
17			.747	.855	.968	1.087	7
18			.836	.964	1.091	1.221	13
19			.932	1.079	1.220	1.360	6
20			1.033	1.197	1.352	1.507	9
21			1.140	1.324	1.497	1.660	7
22			1.255	1.456	1.644	1.823	7
23			1.377	1.599	1.803	1.997	6
24			1.505	1.748	1.981	2.189	2
25				1.909	2.171	2.408	6
26				2.104	2.379	2.661	1
27				2.288	2.592	2.907	2
28				2.484	2.811	3.149	
29				2.692	3.045	3.400	
30				2.885	3.269	3.656	2
Basis							305

Data collected in Gogebic and Wexford Counties, Mich.; Marinette and Vilas Counties, Wis.

Volume includes wood and bark of stem above a 1-foot stump, and in addition all branches suitable for cordwood having a diameter, outside of bark, of 2 inches or more at the middle of a 5-foot stick.

Standard cords 4x4x8 feet; 75 cubic feet per cord.

Table 53

SUGAR MAPLE

(*Acer saccharum*)

Michigan and Wisconsin

Frothingham **1912** **Cubic feet**

Diameter breast high	Total height of tree—feet												Diameter inside bark of top	Basis (trees)	
	50		60		70		80		90		100				
	Volume, including bark—cubic feet														
	Logs	Top	Logs	Top	Logs	Top	Logs	Top	Logs	Top	Logs	Top		Logs	Tops
Inches													*Inches*		
6	0.6	1.8	0.7	2.2	0.8	2.6	1.0	3.0						9	10
7	3.4	1.9	4.2	2.3	5.0	2.7	5.7	3.2						18	17
8	6.5	2.0	7.4	2.5	8.4	2.9	9.4	3.3					6	21	22
9	9.8	2.2	10.4	2.7	11.6	3.0	13.1	3.5					6	35	34
10	13.1	2.4	13.8	2.9	15.2	3.3	17.2	3.7	19.4	4.2			6	23	24
11	16.7	2.6	17.4	3.1	19.3	3.5	22.	4.0	25.	4.5			6	26	26
12	21.0	2.8	21.	3.4	24.	3.8	27.	4.4	30.	4.9	34	5.4	7	25	25
13			26.	3.7	28.	4.2	32.	4.8	36.	5.4	41	6.0	7	20	20
14			30.	4.1	33.	4.8	37.	5.4	42.	6.0	48	6.7	7	22	22
15			35.	4.7	38.	5.4	43.	6.1	49.	6.8	55	7.5	8	16	16
16			40.	5.4	43.	6.3	50.	7.0	56.	7.8	64	8.5	8	22	22
17					49.	7.2	56.	8.0	64.	8.9	72	9.6	9	7	7
18					54.	8.4	63.	9.4	72.	10.2	81	11.0	9	13	13
19					60.	9.8	70.	11.0	80.	11.8	89	12.6	10	6	5
20					66.	11.5	77.	12.7	88.	13.5	99	14.4	10	9	8
21					72.	13.4	85.	14.6	97.	15.5	108	16.5	11	7	6
22					79.	15.6	92.	16.9	105.	17.8	118	19.	12	7	7
23					85.	18.3	100.	20.	114.	21.	128	22.	12	6	6
24					92.	21.0	108.	23.	124.	25.	138	26.	13	2	2
25							116.	27.	133.	30.	149	32.	14	6	6
26							125.	33.	142.	36.	160	40.	15	1	1
27							134.	38.	152.	42.	171	47.	15	2	
28							142.	44.	163.	48.	182	54.	16		
29							152.	50	173.	55.	194	61.	17		
30							161.	55.	184.	61.	206	68.	17	2	
Total														305	299

The "log" volume is the solid contents of wood and bark between a stump height of 1 foot and the "diameter inside bark of top." The volume of "top" is that contained in the stem above this point, and in addition all branches suitable for cordwood having a diameter, outside bark, of 2 inches or more at the middle of a 5-foot stick. The entire volume of trees too small to yield a 6-inch log is considered top wood. Bark comprises about 17 per cent of the total volume; there was no consistent variation with the size of the tree. Trees from Gogebic and Wexford Counties, Mich., and Marinette and Vilas Counties, Wis.

Table 35, U. S. Dept. of Agr. Bul. 285, The Northern Hardwood Forest. 1915.

Table 54

RED, BLACK AND SCARLET OAK

(Quercus sp.)

New York and Connecticut

Frothingham
Barrows

1912

Cubic feet

Diameter breast high	Total height of tree—feet							Basis
	20	30	40	50	60	70	80	
	Volume—cubic feet							
Inches								*Trees*
2	0.3	0.4						26
3		0.9	1.0					55
4		1.5	2.0	2.6				54
5		2.4	2.9	3.6				46
6			4.2	5.0	6.0			38
7			5.7	6.6	7.6	8.9		36
8			7.0	8.5	10.2	12.0		11
9			8.7	10.9	13.0	15.2	17.3	16
10			10.5	13.1	15.7	18.4	21.0	24
11			13.0	16.0	19.0	22.1	25.2	35
12			16.4	19.7	22.8	26.2	29.3	33
13			21.0	24.3	27.7	31.0	34.3	30
14			25.3	29.0	32.6	36.3	40.0	13
15			30.2	34.2	38.1	42.0	45.8	12
16				40.0	44.1	48.2	52.4	5
17						54.6	59.1	4
18						61.0	66.0	2
19						68.0	74.0	1
Basis								441

Volumes include stem and topwood, with bark, up to a minimum diameter of 2 inches. Average stump heights vary from 6 inches for small trees to 21 inches for large ones.

Table 39, U. S. Forest Service Bul. 96, Second Growth Hardwoods in Connecticut. E. H. Frothingham. 1912.

Table 55

RED, BLACK AND SCARLET OAK

(Quercus sp.)

New York and Connecticut

Frothingham
Barrows

1912

Ties
Cubic feet

Diameter breast high	Total height of tree—feet								Basis
	50		60		70		80		
	Ties	Top-wood	Ties	Top-wood	Ties	Top-wood	Ties	Top-wood	
Inches	*No.*	*Cu. ft.*	*No.*	*Cu. ft.*	*No.*	*Cu. ft.*	*No.*	*Cu. ft.*	*Trees*
10	1	8.4	1	10.8	1	12.9	1	15.0	24
11	1	9.0	1	10.8	2	12.6	2	14.2	35
12	2	9.8	2	11.1	2	12.6	3	13.1	33
13	2	11.1	2	12.2	3	12.7	4	12.5	30
14	2	12.3	4	13.0	5	13.1	5	12.4	13
15	4	13.7	4	14.0	5	13.5	7	12.2	12
16	4	15.7	4	15.3	6	14.2	7	12.1	5
17					7	14.6	8	12.1	4
18					8	14.8	10	11.5	2
19					8	15.2	11	11.8	1
Basis									159

All first-class ties, 6 by 8 inches by 8 feet.

NOTE—The volume in "topwood" (top and branches) was obtained by subtracting the aggregate cubic volume of tie logs to a minimum top diameter of 9 inches, outside bark, from the total used volume of the tree, in cubic feet (to a minimum diameter of 2 inches, outside bark).

Table 46, U. S. Forest Service Bul. 96, Second-Growth Hardwoods in Connecticut. E. H. Frothingham. 1912.

Table 56

RED OAK

(Quercus borealis maxima)

Southern Appalachians

Mulford **1906** **Scribner Decimal C**

Diameter breast high	Total height of tree—feet							Diameter inside bark of top	Basis
	40	50	60	70	80	90	100		
	Volume—board feet, in tens								
Inches								*Inches*	*Trees*
8	1.0	1.6	2.6	3.3	4.0	4.6		6	3
9	1.6	2.5	3.7	4.6	5.6	6.3		6	8
10	2.3	3.4	4.9	6.0	7.2	8.3	9.9	6	17
11	3	4.4	6.1	7.6	9.2	11	12	6	14
12	4	5.6	7.4	9.5	11	13	15	6	27
13	5	6.8	8.8	12	14	16	18	7	23
14		8.2	10	14	16	19	21	7	23
15		9.6	12	16	19	22	24	8	27
16		11	14	19	22	25	27	8	13
17		13	17	21	25	29	31	9	14
18			20	24	28	33	36	9	9
19			23	27	32	37	41	10	12
20			26	31	36	41	46	10	4
21				35	41	46	51	11	2
22				39	45	51	57	11	
23				43	50	57	63	12	
24				48	55	63	70	12	1
25				53	60	69	77	13	1
Total									198

Stump height, 1 foot. Based on taper curves; scaled mostly as 16.3-foot logs, with a few shorter logs where necessary.

Table 49, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 57

RED OAK

(Quercus borealis maxima)

Southern Appalachians

Mulford **1906** Scribner Decimal C

Diameter breast high	Number of 16-foot logs									Diameter inside bark of top	Basis
	1	1½	2	2½	3	3½	4	4½	5		
	Volume—board feet, in tens										
Inches										*Inches*	*Trees*
8	2.0	2.7	3	4						6	
9	2.0	3.2	4	5						6	1
10	2.0	3.6	5	6	8					6	2
11	2.1	4.3	6	8	10	12				6	4
12	2.3	5.0	7	9	12	14	18			6	3
13	2.5	5.8	9	11	14	17	20			7	4
14	2.7	6.7	10	13	16	19	23	26		7	9
15	3.0	7.7	12	15	18	22	26	30		8	15
16	3.4	8.9	13	17	20	25	29	34	39	8	18
17	3.8	10	15	19	23	28	32	38	44	9	40
18	4.3	12	17	21	26	31	36	42	49	9	56
19	4.8	13	20	24	29	35	40	47	54	10	65
20	5.4	15	22	27	33	39	45	52	59	10	75
21	6.2	17	25	30	37	44	50	58	65	11	86
22	6.9	19	27	34	41	48	55	64	72	11	90
23	7.7	21	30	38	45	53	61	70	79	12	67
24	8.5	23	34	42	50	58	67	77	86	12	80
25	9.3	25	37	46	55	64	74	84	94	13	56
26	10	28	41	51	60	70	81	91	102	13	89
27	11	30	45	56	66	77	88	99	111	14	68
28	12	33	49	61	72	83	96	108	120	14	81
29	13	56	53	66	78	90	103	116	130	15	61
30	14	39	58	72	85	98	112	125	140	15	47
31		42	63	77	91	105	120	135	151	16	45
32		45	69	83	98	113	129	145	162	16	40
33		48	74	89	105	121	138	156	173	17	49
34			80	95	112	129	148	167	186	17	30
35			86	101	118	138	157	179	199	18	22
36			92	107	125	146	168	191	214	18	17
37				113	132	155	178	204	229	19	24
38				119	139	164	189	217	245	19	11
39				125	146	173	200	230	260	20	16
40				131	154	182	212	243	276	20	15
41					161	191	224	257	293	21	6
42					168	200	236	272	310	21	3
43					175	209	247	286	327	22	3
44					183	218	259	301	345	22	2
Total											1300

Based on taper curves; scaled mostly in 16.3-foot logs, with a few shorter logs where necessary. Height of stump, 2 feet.

Table 48, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 55

WHITE OAK

(*Quercus alba*)

Southern Appalachians

Ashe **1903** **Scribner Decimal C**

Diameter breast high	Number of 16-foot logs									Basis
	1	1½	2	2½	3	3½	4	4½	5	
	Volume—board feet, in tens									
Inches										*Trees*
10	2	3								3
11	2	4								8
12	2	5	7	8						10
13	2	7	9	11						12
14	3	8	11	14	16	18				23
15	3	10	13	16	19	21				41
16	3	11	15	19	22	26	29			31
17	4	13	18	22	26	30	34			39
18	4	15	20	25	30	34	39	44		40
19	5	17	22	28	34	39	44	50	56	75
20	5	19	25	31	38	44	50	56	63	57
21	6	21	28	35	42	50	56	63	70	105
22	7	23	30	39	47	55	62	70	77	96
23	8	25	33	43	52	61	69	77	85	111
24	8	28	36	46	57	66	76	85	93	112
25	9	30	39	50	62	73	83	93	103	106
26	10	32	42	54	67	79	91	103	114	94
27		34	45	58	73	86	99	112	125	97
28		36	48	62	79	94	108	123	137	83
29		39	51	66	86	102	117	133	148	75
30		41	55	70	93	110	127	144	161	56
31			58	75	100	119	137	155	174	56
32			61	79	106	126	146	165	185	36
33			65	84	114	135	158	179	200	21
34			68	89	122	144	168	192	214	23
35				95	129	152	179	204	230	10
36				100	137	160	189	217	245	13
37				106	144	169	200	231	261	9
38					152	178	210	243	278	7
39					160	187	221	258	294	6
40					168	196	232	272	310	1
Total										1436

Stump height, 2 feet. Top diameter inside bark equals one-half the diameter breast high, with a minimum of 5.5 inches. This table is based on taper curves, read every 8.15 feet above stump.

U. S. Forest Service Form 874-aa.

Table 59

SECOND-GROWTH WHITE OAK

(Quercus alba)

Hyde Park, N. Y.

Peters 1905 Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	20	30	40	50	60	
	Cordwood volume—cubic feet					
Inches						*Trees*
2	0.2	0.5				32
3	0.5	0.8	1.1			48
4	0.9	1.4	1.8			71
5		2.3	2.7	3.2		61
6		3.4	4.0	4.8	5.7	44
7		4.8	5.7	6.6	7.9	40
8			7.7	9.0	10.6	26
9				11.8	13.6	4
10				15.3	17.3	8
11				19.6	22.6	7
12				24.6	28.0	7
13					32.2	1
Basis	48	90	106	78	27	349

Volume includes all of the tree that may be utilized for cordwood down to 1 inch in diameter. A cord made up of mixed diameters of second-growth wood is considered to contain 78 cubic feet of solid wood, and this table can be reduced to cords by dividing by 78.

Table 45, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part III.

Table 60

WHITE OAK

(*Quercus sp.*)

New York and Connecticut

Frothingham
Barrows

1912

Diameter breast high	Diameter average stick	Solid contents of cord
Inches		*Cubic feet*
1		
2	1.8	63
3	2.5	69
4	3.1	74
5	3.5	76
6	3.9	79
7	4.2	81
8	4.5	82
9	4.7	83
10	4.9	84
11	5.0	85
12	5.1	85
13	5.2	85
14	5.2	85
15	5.3	86
16	5.4	86

Based on a large number of stacked standard cords 4x4x8 feet, consisting of mixed round and split four-foot wood.

Table 41, U. S. Forest Service Bul. 96, Second Growth Hardwoods in Connecticut. E. H. Frothingham. 1912.

Table 61

JACK PINE

(Pinus banksiana)

Lake States

Wackerman, A. E. **1925** International ⅛ inch kerf.

Diameter breast high	Total height of tree—feet													Top Cu. ft.	Basis
	30	35	40	45	50	55	60	65	70	75	80	85	90		
	Volume—board feet														
Inches															*Trees*
6	4	6	7	9	11	13	16	19	21					1.6	242
7	7	11	14	18	21	25	29	34	35					1.4	227
8		17	21	25	30	34	39	42	48	52				1.3	218
9			28	33	40	44	51	56	62	69				1.1	126
10				42	50	58	64	72	78	86	95	106		1.0	74
11					60	70	81	90	99	108	118	128	139	1.0	58
12						86	98	109	120	132	144	156	169	.9	46
13						103	118	132	145	158	172	187	201	.9	27
14							144	159	175	191	209	226	244	.8	8
15							168	186	204	224	243	264	284	.8	3
16							200	221	242	265	289	312	336	.8	3
Basis															1032

Volume above a 1-foot stump to a top diameter of 5 inches inside bark.
Top cubic feet is the merchantable volume in 8-foot lengths above 5 inches in the top to 3 inches outside bark.
For saws cutting a ¼-inch kerf, reduce the values by 9½ per cent.
Block indicates extent of original data.

Table 62

JACK PINE

(Pinus banksiana)

Lake States

Wackerman, A. E. **1925** Scribner Decimal C

Diameter breast high	Total height of tree—feet											Top Cu. ft.	Basis
	40	45	50	55	60	65	70	75	80	85	90		
	Volume—board feet, in tens												
Inches													*Trees*
7	.2	.5	.8	1.3	1.6	1.9	2.1					2.7	227
8	.8	1.3	1.8	2.4	2.8	3.3	3.8	4.3				2.4	218
9	1.6	2.2	2.8	3.5	4.2	4.7	5.2	5.7				2.2	126
10		3.0	3.7	4.5	5.2	5.9	6.6	7.1	7.7	8.2		2.0	74
11			4.8	5.7	6.5	7.3	8.0	8.8	9.6	10.3		1.8	58
12				7.0	8.0	8.9	9.9	10.8	11.8	12.6	13.6	1.7	46
13				8.2	9.2	10.3	11.3	12.5	13.6	14.5	15.7	1.5	27
14					11.3	12.5	13.8	15.1	16.2	17.6	18.6	1.4	8
15					13.1	14.6	15.9	17.5	18.6	20.2	21.4	1.3	3
16					15.0	16.8	18.5	20.3	21.8	23.5	25.4	1.3	3
Basis													790

Volume above a 1-foot stump to a top diameter of 6 inches inside bark.
Top cubic feet is the merchantable volume in 8-foot lengths above 6 inches in the top to 3 inches outside of bark.
Block indicates extent of original data.

Table 63

JACK PINE

(*Pinus banksiana*)

Cass County, Minnesota

Hansen **1919** Scribner

Diameter breast high	Number of 16-foot logs									
	½	1	1½	2	2½	3	3½	4	4½	5
	Volume—board feet									
Inches										
7	5	20	30	40						
8	5	20	30	50						
9		20	35	50	65	80				
10		20	35	50	65	85	100			
11		20	40	60	80	100	120	140		
12			40	65	85	110	135	160		
13			50	75	100	125	150	175		
14				80	110	140	175	205	235	270
15				90	130	165	200	235	270	310
16					145	185	230	270	310	350
17					155	200	245	290	340	390
18					170	220	270	320	370	420
19					180	230	280	330	380	430
20					190	240	295	345	400	450
21					205	260	315	370	425	480
22						280	340	400	460	520
23						305	370	440	500	570
24						345	410	480	550	620

Revised, 1926.
Top diameter inside bark, 6 inches; Stump height, 9 to 12 inches. Based on 305 trees. Trees scaled as felled.

Table 64

JACK PINE

(*Pinus banksiana*)

Lake States

Wackerman, A. E. **1925** Merchantable cords

Diameter breast high	Total height of tree—feet													Basis	
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
	Unpeeled volume—cords														
Inches															*Trees*
4	.01	.01	.02	.02	.02	.03	.03	.03							151
5	.02	.02	.03	.03	.03	.04	.04	.04	.05	.05					221
6		.03	.04	.04	.05	.05	.06	.06	.07	.07					242
7		.04	.05	.05	.06	.06	.07	.08	.08	.09					227
8			.06	.07	.08	.08	.09	.10	.11	.12	.13	.14			218
9				.08	.09	.10	.11	.12	.13	.14	.15	.16			126
10					.11	.12	.13	.15	.16	.17	.19	.20	.22		74
11						.14	.16	.17	.19	.21	.22	.23	.25	.27	58
12							.19	.21	.22	.24	.26	.27	.29	.31	46
13							.22	.24	.26	.28	.30	.32	.34	.36	27
14								.28	.30	.32	.34	.37	.39	.41	8
15								.31	.34	.36	.39	.41	.44	.47	3
16								.35	.38	.41	.44	.47	.50	.53	3
Basis															1404

Standard cords 4x4x8 feet.

Volume includes stem and bark above a 1-foot stump to a top diameter of 3 inches outside bark.

Compiled from the merchantable volume table in cubic feet by converting by the number of cubic feet of wood per cord—based on D. B. H.

Block indicates extent of original data.

Table 65

JACK PINE

(*Pinus banksiana*)

Lake States

Wackerman, A. E. **1925** Total cubic feet

Diameter breast high	Total height of tree—feet														Form factor	Basis
	25	30	35	40	45	50	55	60	65	70	75	80	85	90		
	Total unpeeled volume—cubic feet															
Inches																*Trees*
3	.8	1.0	1.2	1.3	1.5	1.7	1.8								.67	75
4	1.3	1.6	1.9	2.2	2.4	2.7	3.0	3.2							.62	151
5	2.0	2.4	2.8	3.2	3.5	3.9	4.3	4.7	5.1	5.5					.58	221
6		3.2	3.8	4.3	4.9	5.4	5.9	6.5	7.0	7.6					.55	242
7		4.2	4.9	5.6	6.3	6.9	7.6	8.3	9.0	9.7					.52	227
8			6.1	7.0	7.9	8.7	9.6	10.5	11.3	12.2	13.1				.50	218
9				8.7	9.7	10.8	11.9	13.0	14.1	15.2	16.2				.49	126
10					11.8	13.1	14.4	15.7	17.0	18.3	19.6	20.9	22.2		.48	74
11						15.5	17.1	18.6	20.2	21.7	23.3	24.8	26.4	27.9	.47	58
12							19.9	21.7	23.5	25.3	27.1	28.9	30.7	32.5	.46	46
13							22.8	24.9	27.0	29.1	31.2	33.2	35.2	37.4	.45	27
14								28.9	31.3	33.7	36.5	38.5	40.9	43.3	.45	8
15								32.4	35.1	37.8	40.6	43.2	46.0	48.6	.44	3
16								36.9	40.0	43.0	46.1	49.2	52.2	55.3	.44	3
Basis																1479

Volume includes stump, stem, top, and bark.

Difference between total volume of trees used as a basis and the volumes taken from the table, +.087 per cent.

Block indicates extent of original data

Table 66

JACK PINE

(Pinus banksiana)

Lake States

Wackerman, A. E. **1925** Merchantable cubic feet

Diameter breast high	Total height of tree—feet													Basis	
	25	30	35	40	45	50	55	60	65	70	75	80	85	90	
	Unpeeled volume—cubic feet														
Inches															*Trees*
4	.8	1.0	1.2	1.4	1.6	1.8	2.0	2.1							151
5	1.5	1.8	2.2	2.5	2.7	3.0	3.3	3.6	3.9	4.2					221
6		2.7	3.2	3.6	4.1	4.5	4.9	5.4	5.9	6.4					242
7		3.7	4.3	4.9	5.5	6.1	6.7	7.3	7.9	8.5					227
8			5.5	6.3	7.1	7.8	8.6	9.5	10.2	11.0	11.8	12.6			218
9				7.9	8.8	9.8	10.8	11.8	12.8	13.8	14.7	15.7			126
10					10.8	12.1	13.2	14.4	15.6	16.8	18.0	19.2	20.4		74
11						14.4	15.9	17.3	18.8	20.2	21.7	23.1	24.6	25.9	58
12							18.7	20.4	22.1	23.9	25.5	27.2	28.8	30.5	46
13							21.4	23.4	25.4	27.3	29.3	31.2	33.2	35.1	27
14								27.4	29.7	32.0	34.3	36.6	38.9	41.1	8
15								30.8	33.3	35.9	38.5	41.0	43.7	46.2	3
16								35.4	38.4	41.3	44.3	47.2	50.2	53.1	3
Basis															1404

Volume includes stem and bark above a 1-foot stump to a top diameter of 3 inches outside bark.

Compiled from the total volume table by percentages varying with D. B. H.

Block indicates extent of original data.

Table 67

JACK PINE

(Pinus banksiana)

Western Ontario

Sterrett
Ellis

1911

Ties

Diameter breast high	Total height (average)	Age (average)	Number of ties				Equivalent in board feet
			No. 1, 7″ x 7″ x 8′	No. 2, 6″ x 6″ x 8′	Cull, 5″ x 5″ x 8′	Total	
Inches	*Feet*	*Years*					
10	56	48		0.8	1.1	1.9	37
11	61	55	0.3	2.0	1.0	3.3	74
12	66	62	1.2	1.8	.8	3.8	94
13	70	70	2.2	1.5	.8	4.5	119
14	74	80	3.2	1.5	.4	5.1	145
15	77	91	3.8	1.3	.3	5.4	158
16	81	107	4.0	1.2	.2	5.4	160

Basis, 100 trees.
Table 9, Forest Quarterly, March, 1911.
Table 28, U. S. Dept. of Agr. Bul. 820, The Jack Pine. 1920.

Table 68

RED PINE

(*Pinus resinosa*)

Minnesota, Wisconsin

Chapman
E. S. Bruce
Woolsey

1913

Scribner Decimal C

Diameter breast high	Total height of tree—feet										Basis
	30	40	50	60	70	80	90	100	110	120	
	Volume—board feet, in tens										
Inches											*Trees*
8	1.0	1.3	1.7	3	3	4	5	6			127
9	1.4	2.0	2.8	4	5	6	8	9			144
10	2.0	2.8	4.0	5	7	8	10	12			213
11		3.8	5.3	7	9	11	13	15			256
12		4.8	6.7	9	11	13	15	18	21		315
13		6.0	8.1	10	13	16	18	21	24		351
14		7.0	9.6	12	16	19	21	25	28		345
15			11.0	15	18	22	25	29	32		362
16			13.0	17	21	25	29	33	36	39	338
17			14.0	19	24	29	33	37	41	44	297
18			16.0	22	28	33	38	42	46	50	278
19				26	32	38	43	48	52	56	233
20				29	36	43	49	54	59	63	202
21					40	48	55	61	67	71	178
22					45	54	62	69	75	80	156
23					50	60	68	76	83	89	114
24					55	66	76	85	92	99	98
25					60	72	84	94	102	109	100
26					66	79	92	103	112	120	66
27						86	100	112	122	131	55
28						94	109	122	133	143	13
29						102	117	132	144	156	14
30						109	126	142	156	170	9
31							136	153	169	185	5
32							146	164	182	200	5
33							155	175	196	216	2
34							165	187	210	232	1
Total											4282

Beltrami, Cass, Hubbard, and Itasca Counties, Minn.; Bayfield County, Wis. Height of stump, 2 feet. Top diameter inside bark, 6 inches. Based on taper curves, scaled mostly in 16.3-foot logs, with a few shorter logs where necessary. Table 19, U. S. Dept. of Agr. Bul. 139, Norway Pine in the Lake States. 1915.

Table 69

RED PINE

(Pinus resinosa)

Minnesota, Wisconsin

Chapman
E. S. Bruce
Woolsey

1913 · **Scribner Decimal C**

Diameter breast high	Number of 16-foot logs												Basis	
	Volume—board feet, in tens													
Inches													*Trees*	
8	2.0	3.0	4.0	5									127	
9	2.0	3.4	4.8	6	8								144	
10	2.0	4.1	5.7	7	9	10							213	
11	2.0	4.2	6.2	8	10	12	14						256	
12	2.0	5.2	7.4	9	12	14	16	19					315	
13	2.0	5.6	8.3	11	13	16	18	21	24				351	
14	2.0	6.3	9.6	12	15	18	21	24	27				345	
15		7.1	11.0	14	17	20	23	27	30	34			362	
16		7.8	12.0	15	19	23	26	30	34	38			338	
17			13.0	17	21	25	30	34	39	43	48		297	
18			14.0	19	23	28	33	38	44	49	55		278	
19				20	26	32	38	43	49	55	62	68	233	
20				22	29	35	42	49	55	62	68	75	82	202
21					31	39	47	54	61	68	75	82	88	178
22					34	43	52	60	68	75	82	89	95	156
23					38	48	57	66	74	82	89	96	103	114
24					42	53	63	73	82	90	97	104	111	98
25						60	70	79	89	98	106	113	120	100
26						66	76	86	96	106	114	123	131	66
27						72	83	94	104	114	124	133	143	55
28						79	90	101	112	123	135	145	156	18
29							96	108	120	133	145	158	170	14
30							103	116	130	143	157	171	185	9
31							110	124	139	153	169	184	200	5
32								133	149	165	182	198	214	5
33								142	159	177	195	213	230	2
34								152	171	190	209	228	248	1
Total														4282

Beltrami, Cass, Hubbard, and Itasca Counties, Minn.; Bayfield County, Wis.
Height of stump, 2 feet. Top diameter inside bark, 6 inches. Based on taper curves; scaled mostly in 16.3-foot logs, with a few shorter logs where necessary.
Table 17, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 70

RED PINE

(*Pinus resinosa*)

Itasca County, Minn.

E. S. Bruce — **1902** — Cubic feet

Diameter breast high	Total height of tree—feet							Basis
	40	50	60	70	80	90	100	
	Peeled volume—cubic feet							
Inches								*Trees*
5	2.7	3.3	4.2					6
6	3.8	4.8	5.8					19
7	5.0	6.3	7.8	9.0				34
8	6.5	8.2	10.1	11.9	13.9			26
9	8.1	10.2	12.6	15.0	17.5	19.8		39
10	9.9	12.6	15.3	18.2	21.0	24.0	27	34
11		15.2	18.3	21.0	25.0	29.0	32	38
12		18.2	21.0	25.0	29.0	34.0	38	34
13		21.0	25.0	29.0	34.0	39.0	45	23
14			29.0	33.0	39.0	46.0	52	18
15				37.0	44.0	52.0	60	9
16					51.0	60.0	68	10
17					57.0	67.0	77	5
18					64.0	75.0	86	4
19					71.0	83.0	94	2
20					79.0	91.0	103	2
Basis								303

Table 20, U. S. Dept. of Agr. Bul. 139, Norway Pine in the Lake States. 1915

Table 71

RED PINE

(*Pinus resinosa*)

Minnesota, Wisconsin

Chapman, H. H. **1905** Cubic feet

Diameter breast high	Total height of tree—feet									Basis
	40	50	60	70	80	90	100	110	120	
	Volume—cubic feet									
Inches										*Trees*
7	7.0	8.0	9.5	10.5	11.5					5
8	8.0	9.5	11.5	13.0	15.0					15
9	10.0	12.0	14.0	16.0	18.5					17
10	12.0	14.0	16.5	19.5	22.5	25.5				32
11		17.0	20.0	23.0	27.0	30.5				29
12		19.5	23.5	27.0	31.5	36.5				51
13			27.5	31.5	36.5	43.0	49.5			47
14			32.0	36.5	42.5	49.5	57.5			32
15			37.0	42.0	49.0	56.5	65.0			34
16			42.0	47.5	55.5	63.5	73.0			34
17				53.5	62.0	71.0	81.0			39
18					68.5	78.5	89.0	97.0		40
19					76.0	86.5	97.0	105.0		36
20					83.5	95.0	106.0	114.5		33
21					92.0	103.0	115.0	125.0	139.0	34
22					101.0	112.0	125.0	137.0	153.0	34
23					111.0	122.0	135.0	150.0	167.0	19
24					120.0	131.0	145.0	163.0	182.0	20
25					129.0	142.0	157.0	177.0	197.0	28
26					138.0	152.0	169.0	191.0	214.0	15
27					148.0	162.0	181.0	206.0	230.0	10
28						173.0	193.0	219.0	246.0	4
29						183.0	205.0	233.0	262.0	3
30						193.0	217.0	247.0	277.0	2
Total										613

Itasca County, Minnesota, and Bayfield County, Wisconsin.
This table of volumes includes entire stem except a 1-foot stump.

Table 72

WHITE PINE

(Pinus strobus)

Northern Minnesota

E. S. Bruce **1912** Scribner

Diameter breast high	Total height of tree—feet											Diameter inside bark of top	Basis
	40	50	60	70	80	90	100	110	120	130	140		
	Volume—board feet												
Inches												*Inches*	*Trees*
8	20	25	30	35	45							6	129
9	25	35	45	50	60							6	220
10	35	45	55	65	75	90						6	248
11	40	55	65	80	95	110	125					7	279
12	50	65	80	95	115	130	150					7	279
13	55	75	95	115	135	155	175					7	271
14	65	90	110	135	155	180	205	230				7	234
15		105	130	155	180	210	235	265				7	246
16		120	150	180	210	245	275	300				7	222
17			170	205	240	280	310	345				8	259
18			190	235	275	315	355	390				8	202
19			215	265	310	355	400	440				8	190
20				295	350	400	450	495	535			9	163
21				330	390	450	500	560	600			9	155
22				370	430	500	560	620	670			9	118
23					480	550	620	680	730			10	106
24					530	610	680	750	810	860	920	10	85
25					590	670	750	820	880	950	1020	10	99
26					650	730	810	890	960	1040	1110	11	68
27					710	800	870	960	1040	1130	1210	11	63
28					780	860	940	1030	1120	1220	1310	11	56
29						930	1000	1100	1200	1310	1410	12	37
30						1000	1070	1180	1280	1400	1510	12	37
31							1140	1250	1370	1490	1600	12	36
32							1210	1330	1450	1570	1700	12	24
33							1280	1400	1530	1660	1790	13	23
34							1350	1480	1610	1750	1880	13	15
35							1420	1550	1690	1830	1970	13	12
36							1490	1630	1770	1910	2060	13	8
37							1560	1700	1850	2000	2150	13	4
38							1630	1780	1930	2080	2240	13	3
39								1860	2020	2170	2330	13	6
40								1940	2100	2260	2420	14	3
Total													3899

Height of stump, 0.5-3.5 feet. Deductions for defect made in field.
Table 22, U. S. Dept. of Agr. Bul. 13, White Pine Under Forest Management. 1914.

Table 73

WHITE PINE

(*Pinus strobus*)

Minnesota

Barrows **1913** Scribner Decimal C

Diameter breast high	Total height of tree—feet								Basis
	40	50	60	70	80	90	100	110	
	Volume—board feet, in tens								
Inches									*Trees*
8	2.0	2.7	3.4	4.6	5	6			119
9	2.8	3.5	4.3	5.8	7	8			181
10	3.4	4.4	5.4	7.1	8	10	11		189
11	4.1	5.4	6.8	9	10	12	13		215
12	5.0	6.6	8.2	10	12	14	16	18	198
13	5.8	7.9	9.8	12	14	17	19	21	210
14	6.6	9.3	12.0	14	17	20	22	24	189
15	7.4	11.0	14.0	16	19	23	25	28	54
16	8.3	13	16	19	22	26	28	32	39
17	9.3	15	18	21	25	29	32	36	50
18	10.0	16	20	24	28	32	36	40	49
19		18	23	27	31	36	40	45	67
20		21	26	30	35	40	45	50	38
21			29	33	39	44	49	55	38
22			32	36	43	48	54	61	36
23			35	40	47	53	60	67	31
24			38	43	51	58	66	74	18
25				47	55	64	72	80	24
26				51	60	69	78	88	18
27				55	65	75	85	95	15
28				59	70	81	92	103	11
29				63	75	87	99	112	10
30				67	81	94	107	120	19
31					87	101	115	129	4
32					93	109	124	139	3
33					100	117	133	149	
34					107	126	142	159	2
35					114	135	152	170	1
36					122	144	162	182	1
37						153	173	193	3
38						163	183	205	3
39						173	194	217	2
40						183	205	229	1
41						192	216	242	
42						202	228	255	2
Total									1834

Beltrami, Cass, and Itasca Counties, Minn.

Stump height, 1 foot. Top diameter inside bark, 6 inches. Based on taper curves; scaled mostly in 16.3-foot logs, with a few shorter logs where necessary. Old-growth trees.

Table 11, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 74

WHITE PINE

(Pinus strobus)

Frothingham Barrows — **Minnesota 1913** — **Scribner Decimal C**

Diameter breast high	Number of 16-foot logs												Basis
	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
	Volume—board feet, in tens												
Inches													*Trees*
8	2.8	4.0	5.6	6									119
9	3.1	4.4	6.0	7									181
10	3.6	5.0	6.7	8	10	11							189
11	4.0	5.6	7.4	9	11	13							215
12	4.3	6.3	8.3	10	13	15	18	21					198
13	4.9	7.0	9.4	12	14	17	20	23					210
14	5.3	8.0	11.0	14	17	19	22	25					189
15	5.9	8.9	12.0	15	18	21	24	28					54
16	6	10	13	17	20	24	27	31	34				39
17	7	11	15	19	22	26	30	34	38				50
18	8	12	17	21	25	29	33	37	42	47			49
19	8	14	19	23	27	32	36	41	46	51			67
20	9	15	21	25	30	35	40	45	50	56			38
21		17	23	27	33	38	44	49	55	61			38
22		18	25	30	35	42	48	53	60	66			30
23			27	32	38	45	52	58	65	73			31
24			29	35	41	49	56	63	71	79			18
25				37	44	53	61	68	77	86			24
26				39	47	57	65	74	84	94			18
27					51	61	70	80	91	102			15
28					54	65	75	86	98	109			11
29					57	69	80	92	105	117			10
30					61	73	85	99	112	125	140		19
31						78	91	106	120	134	149		4
32						83	97	113	128	143	158	175	3
33						87	104	121	136	152	168	185	
34						92	111	129	145	162	178	195	2
35							119	137	155	172	189	206	1
36							127	145	164	183	200	218	1
37							135	154	174	193	212	230	3
38							143	163	184	205	225	244	3
39							152	173	194	216	238	259	2
40							162	183	205	228	252	275	1
41							172	193	216	240	267	292	
42							182	203	227	252	282	310	2
Total													1834

Beltrami, Cass, and Itasca Counties, Minn.

Stump height, 1 foot. Top diameter inside bark, 6 inches.

Based on taper curves; scaled mostly in 16.3-foot logs, with a few shorter logs where necessary.

Table 6, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 75

SECOND-GROWTH WHITE PINE

(*Pinus strobus*)

Massachusetts

H. O. Cook — **1908** — Cords

Diameter breast high	Total height of tree—feet						
	30	40	50	60	70	80	90
	Volume—cords						
Inches							
5	0.03						
6	.03	0.04	0.05				
7	.04	.05	.07	0.09			
8	.05	.07	.09	.11	0.13		
9	.07	.09	.11	.13	.16		
10		.11	.13	.16	.19	0.22	
11		.13	.16	.19	.23	.26	0.30
12		.15	.19	.22	.27	.31	.35
13		.17	.22	.26	.31	.36	.40
14			.25	.30	.34	.41	.45
15			.28	.34	.40	.46	.51
16			.32	.38	.44	.52	.58
17				.42	.49	.58	.64
18				.47	.55	.64	.71
19				.51	.60	.70	.79
20				.55	.66	.77	.87
21					.72	.85	.95
22					.78	.92	1.04
23					.84	1.01	1.13
24					.90	1.08	1.22
25					.97	1.16	1.32
26							1.42
27							1.51

Volume includes bark; stump height, 6 inches; top diameter, 4 inches.
Volume scaled by the Humphrey caliper rule for stacked cordwood.
From "Forest Mensuration of White Pine in Massachusetts."

Table 76

SECOND-GROWTH WHITE PINE

(Pinus strobus)

Southern New Hampshire

L. Margolin — Cubic feet

Diameter breast high	Total height of tree—feet										Basis
	Total volume—cubic feet										
	30	40	50	60	70	80	90	100	110	120	
Inches											*Trees*
5	2.3	3.0	3.6								7
6	3.0	4.3	5.1	6.0	6.5						41
7	4.1	5.7	6.9	8.2	9.2						75
8	5.4	7.1	8.8	10.5	12.2	13.9	15.8				128
9	6.9	8.8	10.9	13.0	15.4	17.8	20.2				156
10	8.6	10.5	13.1	15.8	18.9	21.9	25.0				177
11		12.3	15.5	18.7	22.5	26.1	29.9				164
12		14.3	18.0	22.0	26.4	30.8	35.0	40.1	45.9		146
13		16.3	20.7	25.3	30.4	35.4	40.1	45.8	52.0		137
14			23.7	29.1	34.8	40.2	45.8	51.7	58.8		89
15			27.0	33.1	39.2	45.3	51.9	58.0	65.8		61
16			30.7	37.5	44.3	51.0	58.1	65.1	73.7		88
17			35.0	42.3	49.9	57.0	65.1	73.1	82.5		68
18			40.0	47.6	55.5	63.9	72.2	82.0	92.1	104.2	68
19				53.0	60.2	70.9	80.0	91.0	102.1	114.8	43
20					67.1	78.1	88.1	100.2	112.2	125.6	34
21					73.1	85.7	96.7	109.2	122.1	136.3	21
22					79.1	93.1	105.3	118.1	131.7	146.7	16
23						101.0	113.6	127.0	140.5	156.1	18
24						108.6	121.8	135.8	149.8	165.5	8
25						115.8	129.8	144.2	159.0	174.6	12
26						122.7	137.8	153.1	168.5	183.2	11
Total											1568

Volume includes stump, stem, top, and bark.

Table 26, U. S. Dept. of Agr. Bul. 13, White Pine under Forest Management, E. H. Frothingham. 1914.

Table 77

BLACK SPRUCE

(Picea mariana)

New York

Belyea **1922** Cords

Diameter breast high	Total height of tree—feet						
	20	30	40	50	60	70	80
	Volume—cords						
Inches							
4	.015	.018	.023				
5	.024	.030	.036	.045			
6	.035	.041	.050	.062	.082		
7		.056	.066	.082	.105		
8		.071	.084	.103	.132	.158	
9			.104	.126	.161	.182	
10			.127	.159	.188	.200	.230
11			.149	.171	.199	.226	.256
12			.171	.195	.226	.257	.295
13				.219	.256	.302	.348
14				.256	.297	.355	.412
15				.289	.341	.423	.489

Utilization to 3-inch top, average height of stump, 1 foot.
Based on 748 trees collected at Cranberry Lake, N. Y.
Table 64, New York State College of Forestry, Bul. No. 14, H. C. Belyea, O. M. Porter.

Table 78

BLACK SPRUCE

(*Picea mariana*)

New York

Belyea **1922** Cubic feet

Diameter breast high	Total height of tree—feet						
	20	30	40	50	60	70	80
	Total volume—cubic feet						
Inches							
4	1.48	1.78	2.31				
5	2.42	2.97	3.52	4.43			
6	3.46	4.07	4.95	6.20	8.17		
7		5.53	6.57	7.75	10.35		
8		7.04	8.32	10.15	12.97		
9			10.35	12.42	15.95	17.80	
10			12.55	15.85	18.65	19.80	22.75
11			14.78	16.95	19.70	22.30	25.30
12			16.95	19.25	22.20	25.35	29.12
13				21.40	25.30	29.80	34.15
14				25.30	29.45	35.15	40.65
15				28.55	34.25	41.85	48.45

Based on 748 trees collected in St. Lawrence County, New York.
Table 62, New York State College of Forestry, Bul. No. 14, H. C. Belyea, O. M. Porter.

Table 79

BLACK SPRUCE

(*Picea mariana*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R.

1920

Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Total volume—cubic feet					
Inches						*Trees*
5	2.6					28
6	3.8	5.0				73
7	5.4	6.5	7.5			104
8	7.5	7.7	9.7	10.7		111
9		11.2	12.3	13.8		68
10		13.8	15.3	16.8	18.0	39
11		17.0	18.3	20.0	21.6	18
12			21.5	23.5	25.6	7
13			25.0	27.5	30.1	3
14			28.8	31.8	34.9	4
15					40.0	1
Basis						456

Softwood Type.
Data collected in the Agawa River Valley, Twp. 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving average values on D. B. H. and height.

Table 80

BLACK SPRUCE

(*Picea mariana*)

New York

Belyea 1922 Cubic feet

Diameter breast high	Total height of tree—feet						
	20	30	40	50	60	70	80
	Volume—cubic feet						
Inches							
4	1.35	1.62	2.10				
5	2.20	2.70	3.20	4.03			
6	3.15	3.70	4.50	5.63	7.42		
7		5 02	5.97	7.40	9.42		
8		6.40	7.55	9.25	11.75		
9			9.40	11.30	14.50	16.20	
10			11.40	14.40	16.95	18.00	20.70
11			13.45	15.40	17.90	20.25	23.00
12			15.40	17.50	20.20	23.05	26.50
13				19.80	23.00	27.10	31.00
14				23.00	26.80	32.00	37.00
15				26.00	30.75	38.00	44.00

Utilization to a 3-inch top. Average height of stump, 1 foot.
Based on 748 trees collected in St. Lawrence County, New York.
Table 63, New York State College of Forestry, Bul. 14, H. C. Belyea, O. M. Porter.

Table 81

BLACK SPRUCE

(*Picea mariana*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R. **1920** Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Used volume—cubic feet					
Inches						*Trees*
5	2.0	2.5				28
6	2.6	3.5	4.7			73
7	3.5	4.9	6.2	7.2		104
8	4.5	6.2	7.9	9.3		111
9		7.9	9.7	11.4		68
10		9.6	11.7	13.6		39
11			14.0	16.2	18.9	18
12			16.5	19.0	21.9	7
13			19.6	22.0	25.4	3
14			22.6	25.5	29.1	4
15				29.6	33.2	1
Basis						456

Softwood Type.
Data collected in the Agawa River Valley, Twp. 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving average values on D. B. H. and height.

Table 82
WHITE SPRUCE
(Picea glauca)
Minnesota
1926

T. S. Hansen — Merchantable cords

Diameter breast high	Total height of tree—feet																		Basis	
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	
	Unpeeled volume—cords																			
Inches																				*Trees*
6	.03	.04	05	.05	.06															1
7	.04	.05	.06	.06	.07	.08	.09	09	.10											12
8		.06	.07	.08	.09	.10	.11	.12	.13	.14	.15									29
9		.08	.09	.11	.11	.13	.14	.15	.16	.17	.18	.19								36
10			.11	.12	.14	.15	.17	.18	.19	.21	.22	.23	.25							42
11				.14	.16	.18	.20	.21	.23	.24	.26	.28	.29							23
12				.17	.19	.21	.23	.24	.26	.28	.30	.32	.34							45
13				.20	.22	.24	.26	.28	.30	.32	.34	.37	.40	.41						19
14					.25	.27	.29	.32	.34	.37	.40	.42	.45	.48	.50					31
15					.27	.30	.33	.36	.38	.42	.45	.48	.50	.53	.55					22
16						.34	.38	.42	.43	.48	.50	.53	.55	.59	.62					17
17						.38	.42	.45	.50	.53	.55	.59	.62	.67	.71	.77				10
18						.43	.48	.50	.55	.59	.62	.67	.71	.77	.77	83	.83			12
19						.48	.53	.55	.59	.62	.67	.71	.77	.83	.83	.90	90	1.00		12
20							55	.62	.67	.71	.77	.83	.83	.90	.90	1.00	1.00	1.11	1.11	3
21							.62	.67	.71	.77	.83	.83	.90	1.00	1.00	1.11	1 11	1.25	1.25	7
22							.67	.71	.77	.83	.90	.90	1.00	1.00	1.11	1.11	1.25	1.25	1.43	
Basis																				321

Standard cords 4x4x8 feet.
Unpeeled volume above a 1.5 foot stump to a top diameter outside of bark of 3 inches.
Compiled from the merchantable cubic feet volume table and a table for Jack pine giving the number of cubic feet per cord by D. B. H. classes. Data collected in Beltrami County in 1917 by J. H. Allison.
Block indicates extent of original data.

Table 83

WHITE SPRUCE

(Picea glauca)

Minnesota

1926

T. S. Hansen — Total cubic feet

Diameter breast high	Total height of tree—feet																		Basis	
	Total volume—cubic feet																			
Inches																			*Trees*	
6	3.3	3.9	4.5	5.0	5.6	6.1	6.7												1	
7	4.4	5.1	5.9	6.6	7.3	8.1	8.8	9.5	10.3										12	
8		6.6	7.5	8.5	9.4	10.4	11.3	12.3	13.2	14.1	15.1								29	
9		8.2	9.4	10.5	11.7	12.9	14.0	15.2	16.4	17.5	18.7	19.9							35	
10			11.3	12.8	14.2	15.6	17.0	18.5	19.8	21.3	22.7	24.1	25.5						42	
11				15.1	16.8	18.5	20.2	21.9	23.5	25.2	26.9	28.6	30.1						23	
12				17.6	19.6	21.6	23.6	25.5	27.5	29.4	31.4	33.4	35.3						45	
13				20.4	22.7	25.0	27.2	29.5	31.9	34.2	36.4	38.6	40.8	43.2					19	
14					25.9	28.5	31.2	33.7	36.2	38.9	41.6	44.0	46.7	49.2	51.7				31	
15					29.4	32.4	35.4	38.3	41.2	44.2	47.1	50.1	53.1	55.9	58.8				22	
16						36.5	39.8	43.1	46.4	49.7	53.0	56.3	59.6	63.0	66.2				17	
17						40.7	44.5	48.2	52.0	55.6	59.3	62.8	66.6	70.2	74.0	77.7			10	
18						45.1	49.4	53.4	57.5	61.6	65.7	70.0	74.0	78.0	82.1	86.4	90.5		12	
19						49.6	54.1	58.5	62.9	67.5	72.1	76.6	81.2	85.6	90.0	94.5	99.2	103.9	12	
20							59.2	64.2	69.1	74.1	79.0	84.0	89.0	93.8	98.9	103.8	108.6	114.0	118.6	3
21							64.2	69.6	75.0	80.2	85.6	91.1	96.5	101.9	107.2	112.6	117.9	123.2	128.5	7
22							69.7	75.5	81.2	87.0	92.9	98.4	104.1	110.0	116.0	122.1	128.0	133.6	139.5	
Basis																			321	

Volume includes stump, stem, and bark.
Compiled by the Form Factor Method from data collected in Beltrami County in 1917 by J. H. Allison.
Difference between total volume of trees used as a basis and volumes taken from table, 0.3 per cent.
Block indicates extent of original data.

Table 84

WHITE SPRUCE

(*Picea glauca*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R.

1920

Cubic feet

Diameter breast high	Total height of tree—feet						Basis
	40	50	60	70	80	90	
	Total volume—cubic feet						
Inches							*Trees*
5	2.6						
6	4.2	4.8					33
7	5.8	6.6	7.5				62
8	7.7	8.7	10.3	11.7			80
9	10.0	11.3	12.9	14.7			100
10		13.8	15.6	17.7	20.4		125
11		17.0	18.7	21.0	24.0		134
12			22.0	24.5	27.7		104
13			25.7	28.3	32.0		69
14			29.7	32.4	36.3	41.5	50
15				36.8	41.0	46.5	30
16				41.5	46.3	52.0	26
17					52.0	58.2	7
18					58.3	64.6	4
19						72.0	6
Basis							834

Softwood Type.
Data collected in the Agawa River Valley Twp. 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving average values on D. B. H. and height.

Table 85

WHITE SPRUCE

(*Picea glauca*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R.

1920

Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Total volume—cubic feet					
Inches						*Trees*
7	5.8	6.3	6.8			40
8	7.5	8.6	9.6			42
9	9.5	11.2	12.6			49
10		14.1	16.0	17.0		54
11		17.3	19.5	20.9		57
12			23.1	25.0	26.8	42
13			27.2	29.3	31.3	39
14			31.8	34.0	36.0	32
15			36.5	39.0	41.3	15
16				44.5	47.0	5
17					53.3	6
18					59.8	2
19					66.0	3
Basis						386

Mixed Type.
Data collected in the Agawa River Valley Twp. 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.
Compiled by curving average values on D. B. H. and height.

Table 86

WHITE SPRUCE

(*Picea glauca*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R.

1920

Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Total volume—cubic feet					
Inches						*Trees*
6	3.6					33
7	5.6	6.5	7.1			102
8	7.8	8.8	9.9			144
9		11.5	12.9	14.5		159
10		14.5	16.0	17.5		167
11			19.6	21.0		166
12			23.2	24.8	27.7	122
13			27.2	28.8	32.0	84
14			31.6	33.2	36.6	64
15				38.3	41.7	36
16				44.0	47.3	26
17					53.5	6
18					59.5	6
19					65.6	3
Basis						1118

All Types.

Based on data collected in the Agawa River Valley, Twp. 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.

Compiled by curving average values on D. B. H. and height.

Table 87

WHITE SPRUCE

(Picea glauca)

Minnesota

1926

T. S. Hansen — Merchantable cubic feet

Diameter breast high	Total height of tree—feet																		Basis	
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	
	Unpeeled volume—cubic feet																			
Inches																				*Trees*
6	2.9	3.4	3.9	4.4	4.8	5.3	5.8													1
7	4.0	4.7	5.3	6.0	6.6	7.3	8.0	8.7	9.3											12
8		6.1	6.9	7.8	8.7	9.5	10.4	11.3	12.2	13.0	13.9									29
9		7.6	8.7	9.8	10.9	11.9	12.9	14.1	15.2	16.3	17.4	18.4								35
10			10.6	11.9	13.3	14.6	15.9	17.2	18.5	19.9	21.2	22.5	23.8							42
11				14.1	15.7	17.3	18.9	20.5	22.0	23.6	25.2	26.8	28.2							23
12				16.5	18.4	20.2	22.1	23.9	25.8	27.6	29.4	31.2	33.2							45
13				19.2	21.3	23.2	25.6	27.7	29.9	32.0	34.1	36.2	38.3	40.6						19
14					24.3	26.7	29.2	31.6	34.0	36.5	39.0	41.2	43.7	46.6	48.5					31
15					27.6	30.3	33.2	35.9	38.6	41.5	44.2	47.0	49.7	52.4	55.1					22
16						34.3	37.4	40.5	43.6	46.7	49.7	52.8	56 0	59.1	62.2					17
17						38.3	41.8	45.4	48.9	52.2	55.7	59.1	62.6	66.0	69.5	73.1				10
18						42.4	46.5	50.2	54.1	58.0	61.8	65.7	69.5	73.4	77.1	81.1	85.0			12
19						46.6	50.9	55.0	59.1	63.5	67.8	72.1	76.2	80.5	84.6	88.9	93 2	97.5		12
20							55.6	60.4	65.0	69.6	74.4	79.0	83.6	88.2	92.9	97.7	102 2	107.0	111.1	3
21							60.2	65.5	70.4	75.4	80.5	85.6	90.6	95.6	100.9	105.8	110.9	116.0	120.9	7
22							65.5	71.0	76.4	81.8	87.2	92.4	98.0	103.6	109.0	114.7	120.2	125.6	131.2	
Basis																				321

Volume above a 1.5-foot stump to a 3-inch top diameter outside of bark.

Compiled by expressing merchantable volume as a percentage of total volume and curving these values on D. B. H. Data collected in Beltrami County in 1917 by J. H. Allison.

Block indicates extent of original data.

Table 88

WHITE SPRUCE

(Picea glauca)

Minnesota

1926

T. S. Hansen — **Merchantable cubic feet**

Diameter breast high	Total height of tree—feet																		Bark per cent	Basis	
	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120		
	Peeled volume—cubic feet																				
Inches																				*Trees*	
6	2.3	2.7	3.1	3.5	3.9	4.3	4.7												19.6	1	
7	3.3	3.8	4.4	4.9	5.5	6.0	6.6	7.2	7.7										17.5	12	
8		5.1	5.8	6.6	7.3	8.0	8.8	9.5	10.2	10.9	11.7								16.0	29	
9		6.5	7.4	8.3	9.3	10.2	11.1	12.1	13.0	13.8	14.8	15.8							14.5	35	
10			9.1	10.3	11.5	12.6	13.8	14.9	16.0	17.2	18.3	19.5	20.6						13.5	42	
11				12.4	13.8	15.1	16.5	17.9	19.2	20.6	22.0	23.2	24.3						12.5	23	
12				14.5	16.2	17.8	19.4	21.0	22.6	24.3	25.9	27.5	29.2						12.0	45	
13				17.0	18.9	20.6	22.6	24.5	26.5	28.3	30.2	32.0	33.9	36.0					11.5	19	
14					21.6	23.8	26.0	28.1	30.2	32.5	34.7	36.7	39.0	41.5	43.2				11.0	31	
15					24.6	27.0	29.6	32.0	34.4	36.9	39.3	41.8	44.3	46.6	49.0				11.0	22	
16						30.7	33.4	36.2	39.0	41.7	44.5	47.2	50.1	53.0	55.7				10.5	17	
17						34.2	37.4	40.6	43.7	46.7	49.9	53.0	56.0	59.1	62.2	65.5			10.5	10	
18						38.0	41.6	45.0	48.5	51.9	55.4	58.7	62.2	65.6	69.0	72.6	76.1		10.5	12	
19						41.8	45.5	49.3	53.0	56.9	60.7	64.6	68.4	72.1	75.9	79.5	83.5	87.4	10.4	12	
20							50.0	54.2	58.4	62.5	66.7	71.0	75.1	79.3	83.4	87.9	92.0	96.1	100.0	10.2	3
21							54.2	58.9	63.3	67.7	72.5	77.0	81.5	86.0	90.6	95.0	99.6	104.3	108 5	10.1	7
22							59.0	63.9	68.7	73.6	78.5	83.1	88.2	93.1	98.0	103.1	108.4	113.0	118.2	10.0	
Basis																				321	

Peeled volume above a 1.5-foot stump to a 3-inch top diameter outside of bark.

Compiled by reducing the unpeeled merchantable volume in cubic feet by means of bark percentages based on D. B. H. Data collected in Beltrami County in 1917 by J. H. Allison.

Block indicates extent of original data.

Table 89

WHITE SPRUCE

(*Picea glauca*)

Algoma District, Ontario

McCarthy, E. F.
Mills, C. R.

1920

Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	40	50	60	70	80	
	Used volume—cubic feet					
Inches						*Trees*
6	3.0	3.2	3.6			33
7	4.4	4.8	5.6			102
8	6.0	7.0	8.0			144
9	8.0	9.5	10.8	11.7		159
10	10.2	12.2	13.8	14.9		167
11	12.6	15.2	18.2	18.3	19.6	166
12		18.5	20.8	22.0	23.5	122
13			24.6	26.4	27.8	84
14			28.7	30.8	32.6	64
15			33.0	35.5	37.6	36
16				40.5	43.0	26
17					49.0	6
18					55.0	6
19					61.0	3
Basis						1118

All Types.

Average stump height, 1.9 feet. Average top diameter inside bark, 5.5 inches; Data collected in the Agawa River Valley, Twp 27, R. 20, Table of the Forestry Branch, Interior Dept., Canada.

Compiled by curving averages on height and D. B. H.

Table 90

TAMARACK

(*Larix laricina*)

St. Louis County, Minn.

Chapman **1905** Scribner Decimal C

Diameter breast high	Total height of tree—feet						Basis
	50	60	70	80	90	100	
	Volume—board feet, in tens						
Inches							*Trees*
8	2.3	2.9	4	5	5		27
9	3.0	3.9	5	6	7		49
10	3.9	5.1	6	8	9	10	127
11	4.8	6.3	8	10	11	13	96
12	5.8	7.6	9	11	13	15	122
13	6.9	8.9	11	13	16	18	48
14	8.0	10.0	13	15	18	21	38
15		12.0	15	18	21	24	21
16		13.0	16	20	23	27	6
17			18	22	26	30	1
18			20	25	29	34	3
19				27	32	37	
20				30	35	41	
Basis							538

Close utilization to top diameter of 5.5 inches inside bark, Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs. Stump height, 1 foot.

Table 101, U. S. Dept. of Agr. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 91

TAMARACK

(*Larix laricina*)

St. Louis County, Minn.

Chapman **1905** Scribner Decimal C

Diameter breast high	Number of 16-foot logs									Basis
	1	1½	2	2½	3	3½	4	4½	5	
	Volume—board feet, in tens									
Inches										*Trees*
8	1.4	2.8	3.9	5.3	7					27
9	1.8	3.2	4.6	6.0	8					49
10	2.1	3.6	5.2	6.8	9	10	11			127
11		4.1	5.8	7.6	10	11	13			96
12		4.6	6.5	8.4	11	12	15	17		122
13			7.2	9.3	12	14	17	20		48
14			7.9	10.0	13	15	19	22	26	38
15				11.0	14	17	21	24	28	21
16				12.0	15	19	23	26	31	6
17					17	21	25	29	33	1
18					18	22	27	31	36	3
19						24	29	34	39	
20						26	31	36	41	
Total										538

Close utilization to diameter of 5.5 inches inside bark at top. Scaled from taper curves, mostly in 16.3-foot logs, with a few shorter logs. Stump height, 1 foot.

Table 100, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 92

TAMARACK

(*Lariz laricina*)

St. Louis County, Minn.

Chapman | **1905** | Cubic feet

Diameter breast high	Total height of tree—feet					Basis
	60	70	80	90	100	
	Peeled volume—cubic feet					
Inches						*Trees*
7	8.5	10.0				1
8	10.5	12.0				11
9	13.0	14.5	16.0			36
10	15.0	17.0	19.5	23.0	27.0	62
11		20.0	23.0	26.5	31.0	47
12		23.5	26.5	30.5	35.0	48
13		27.0	30.5	34.5	39.5	23
14		31.0	34.5	38.5	44.0	12
15			38.5	43.0	49.5	6
Total						246

Table 102, U. S. Dept. of Agr. Bul. Volume Tables for the Important Timber Trees of the United States. Part II.

Table 93

TAMARACK

(*Lariz laricina*)

St. Louis County, Minnesota

H. H. Chapman **1905**

Diameter breast high	Number of ties			Basis
	7″x7″x8′	6″x6″x8′	Cull	
Inches				*Trees*
8			2.00	17
9	0.02	0.19	1.59	59
10	.13	1.15	1.21	111
11	.80	1.35	.90	121
12	1.73	1.38	.65	115
13	2.53	1.33	.48	64
14	3.10	1.20	.34	41
15	3.56	1.05	.43	22
16	3.97	.91	.55	6
17	4.34	.79	.68	1
18	4.68	.68	.83	3
Basis				560

TECHNICAL BULLETIN 40 JUNE 1926

University of Minnesota
Agricultural Experiment Station

Studies of Self-Fertilization in Rye

By H. E. Brewbaker
Division of Farm Management, Agronomy, and Plant Genetics

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	2
Mode of rye pollination	4
Source and history of material used	5
Inbreeding through self-fertilization	8
Early studies fo self-fertilization in rye	8
Studies of seed setting within a single floret and between nearby florets on the same head	10
Method used and results obtained from self-fertilization in Minn. No. 2 rye	13
Utilization of selfed strains for the production of improved varieties	26
Summary	29
Literature cited	30
Appendix	33

ILLUSTRATIONS

	Page
Fig. 1. Minn. No. 90, a colorless strain of rye grown in an isolated plot	6
Fig. 2. Plot in which artificial self-pollination studies were made in 1922	14
Fig. 3. Encaged selfing plot in 1925	15
Fig. 4. Stubble of brittle plants as commonly broken off by the wind	18
Fig. 5. Types of reaction of Minn. No. 2 rye to *P. graminis secalis*	23
Fig. 6. A homozygous susceptible strain	23
Fig. 7. Relative vigor of seedlings	24
Fig. 8. Comparison of height of mature plants	25
Fig. 9. Comparison under field conditions of selfed strains and Minn. No. 2	27
Plate I. Details of rye inflorescence	33

STUDIES OF SELF-FERTILIZATION IN RYE[1]

H. E. Brewbaker[2]

INTRODUCTION

Cultivated rye, *Secale cereale* L., is considered by Schulz (26) to have descended from *Secale anatolicum* Boissier, which is found at the present time growing wild in Syria, Armenia, Persia, Afghanistan, Turkestan, Sungari, and the Kirghiz Steppe. It is supposed to have come into cultivation in Turkestan. Engler-Gilg (4) considers *S. cereale* to have originated from *S. montanum*, a wild species growing in Southern Europe and the adjoining part of Asia, and to have been grown first as a cultivated plant in the Bronze Period. Vavilov (31, 32) believes the morphological or physiological similarity between *S. montanum* and *S. cereale* insufficient evidence to prove that the one originated from the other. *S. cereale* is found as a weed widely distributed among wheat and barley plantings throughout the southwest of Asia, where rye has never been grown as a cultivated crop. This rye-weed appears to be indigenous in this section of Asia. Vavilov believes that seed of this rye-weed was intentionally sown with wheat and barley and that when the value of the rye became fully appreciated it was sown as a separate crop.

Rye is now one of the world's great cereal crops. The total production of rye[3] for the three-year period, 1922-24, averaged slightly more than one billion bushels per year. This was a little less than the production of barley, about one-third that of wheat, and a little more than one-fourth that of oats. The United States during this time produced about 7.5 per cent of the total world production, or an average of more than 76 million bushels per year. Minnesota raises approximately one-fifth of the rye grown in the United States. In 1924 about 4.5 per cent of the crop land in this state was planted to rye. Rye does not usually outyield a hardy winter wheat, but on dry land and poor soils, or in seasons when black stem rust is a limiting factor in wheat production, it generally yields more than spring wheat. Rye is especially valuable throughout the Corn Belt for late autumn and early spring pasture, as a green manure crop, and as a companion crop with alfalfa and clover. Whether or not rye will become of increasing importance in the United States depends somewhat upon the development of high-yielding commercial varieties.

[1] A thesis submitted to the faculty of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy. 1926.

[2] Grateful acknowledgment is made to Dr. H. K. Hayes, under whose direction the studies were made; to Dr. E. C. Stakman and Dr. M. N. Levine for help in connection with the rust reaction phase of the problem; and to Mr. Lee Alexander for general assistance.

[3] See Yearbook of the U. S. Dept. of Agr. for 1924.

Improvement in rye has been accomplished largely through mass selection and, to a lesser extent, by individual plant selection. The necessity of controlling the male as well as the female parentage in breeding heterozygous plant material is appreciated now as it has not been in the past.

The purpose of this investigation was to study the effects of self-fertilization in rye and the possibility of the use of inbred lines as foundation material for further improvement.

MODE OF RYE POLLINATION

In initiating a breeding attack on any crop it is of fundamental importance to know the natural mode of reproduction and the extent to which self-pollination or cross-pollination takes place. The rye flower is especially well adapted for cross-pollination (see Plate I). According to Hildebrand,[4] the anthers project between the partly closed glumes until their bases emerge. They then tip over and dehisce, spilling the pollen outside the flower. Fruwirth (7), on the other hand, states that the filament lengthens rapidly and forces the anther out of the flower; and that dehiscence begins before the anther has tipped over. Thus a small amount of pollen may fall on the stigma of the same flower while the larger part is carried away.

Observations on anthesis were made by the writer on several plants which were grown in the field, transplanted into flats, and brought into the laboratory. Florets located slightly above the center of the head are usually the first to open, flowering proceeding in both directions. Opening of the floret starts slowly and gradually increases in rapidity until the anthers finally emerge and dehiscence has taken place, the whole process requiring about an hour. Dehiscence was found to take place rarely before the anthers were extruded and tipped over, and in some of these exceptional cases the anther was found to catch temporarily on the awn of a lower floret. Self-pollination is made improbable by the late dehiscence of the anthers, and the large feathery stigma (Plate I a, b, c) offers splendid opportunity to catch foreign pollen carried by the wind. After artificial pollination with pollen from another plant, the floret closed completely in 45 minutes. If cross-pollination was not effected the floret stayed open much longer. Heribert-Nilsson (14) found the stigma receptive 14 days after blossoming. The writer found the unfertilized florets to remain open as long as 19 days in the greenhouse. The florets finally close whether or not fertilization is accomplished. It is concluded from these observations that natural cross-pollination is greatly favored, but that self-pollination is not prevented.

[4] See Knuth's Handbook of Flower Pollination, Vol. III, pp. 531-32.

Heribert-Nilsson (16), in a test of vicinism, or natural crossing between plants, used a wax-free strain as the "indicator." The wax-free character is a simple Mendelian recessive, hence any natural crossing between wax-free and normal plants when the normal is the pollen parent, will be apparent in the F_1 generation. A single indicator plant was separated from a plot of 3500 square meters of normal rye, with the following results:

Separated by	50	meters	— 54.5%	natural	crossing
" "	250	"	— 46.3%	"	"
" "	350	"	— 29.7%	"	"
" "	400	"	— 19.0%	"	"

Single indicator plants separated by 50 meters from a small plot of 10 square meters of normal rye were cross-pollinated by normal rye to the extent of 10 per cent.

While the vicinism experiment of Heribert-Nilsson was not designed to determine the degree of natural crossing which takes place within a variety, the results obtained, when considered in relation to the flower structure and anthesis, and the high degree of self-sterility in rye, justify the conclusion that rye is to a very large extent naturally cross-pollinated.

SOURCE AND HISTORY OF MATERIAL USED

Minnesota No. 2 rye was used for all the investigations herein reported. This variety was developed from the well known Swedish variety, the original stock having been obtained in 1895 from John Brogard, at Henning, Minn. Plants which survived the winters of 1896-97 and 1897-98 were used as foundation stock. In 1897, 120 seeds were planted in the nursery, from which 16 plants were harvested in 1898. These few plants were the original source of the variety now known as Minnesota No. 2, which excels in winterhardiness (see Boss, 1).

In 1916, a selection experiment was planned by Dr. H. K. Hayes for the purpose of obtaining varieties with more uniform color of grain. Individual plants were selected on the basis of plant vigor in the field and later for grain color and plumpness in the laboratory, and the seed of each selected mother plant was sown in a small isolated plot, using 50 to 75 seed for each plot. These plots were located among the winter wheat nursery plots and were separated from each other by a distance of 50 to 100 feet or more, depending upon the space available and the number of strains to be isolated. Continuous selection has been carried on since 1916.



Fig. 1. Minn. No. 90, a Colorless Strain of Rye Grown in an Isolated Plot
This strain was produced as a result of five years continuous selection in Minn. No. 2 Rye.

While it is not the intention to give a complete report of this selection experiment, certain facts appear of interest in relation to the self-fertilization studies. Indications of approaching homozygosity through inbreeding are apparent, not alone in relative purity for grain color, for which selection was made, but also in relation to the occurrence of increased numbers of certain types of seedling and plant abnormalities in some strains and the comparative freedom from others (see Table I). Minnesota No. 92, a strain having dark green seed, produces many more white seedlings than does normal Minn. No. 2; the same is true to a lesser extent of Minn. No. 91, a light green seeded strain. In contrast to this, Minn. No. 90 (Fig. 1), a colorless seeded strain, appears to be practically free from white seedlings, only one having been found since 1923. During the same time yellow-green seedlings were found quite frequently in Minn. No. 90, while none have been recorded in Minn. No. 92 (see Tables I and VII). The results obtained in relation to purity for grain color corroborate to a considerable extent those of von Rumker (23, 24, 25), who obtained several pure color types as a result of continuous selection for seven or eight years.

TABLE I

OCCURRENCE OF SEEDLING AND PLANT ABNORMALITIES IN THE "SELECTION" STRAINS, COMMERCIAL MINN. NO. 2, AND A RECOMBINATION VARIETY
Rod Row Test

Nursery stock No.	1923		1924		1925		1926	
	Total	Per cent abnormalities*	Total	Per cent abnormalities*	Total	Per cent abnormalities*	Total	Per cent abnormalities*
1-22-5	1237	None	1647	None	2249	0.2 yg	1650	None
1-22-6	1414	10.4 w	1361	10.2 w	1672	4.6 w 0.06 st	1336	0.8 w 0.2 vw
1-22-8	1373	6.6 w	1404	2.1 w 6.3 yg	1809	0.3 w 5.3 yg		Discarded
1-22-10	1395	1.3 w	1478	None	1622	None	1300	None
1-22-11	1211	2.3 w	1406	None	1921	0.05 cyl 4.7 w	1300	None
1-22-12	1236	1.6 w	1885	2.0 w 1.3 yg	2358	1.5 w 1.1 yg	1600	0.6 w
1-22-13	1336	1.0 w	3542	1.0 w 0.8 yg	2765	0.8 w	1780	0.6 w
1-22-14	1468	2.0 w	2422	1.5 w 0.3 vw	2136	1.0 w 0.1 yg	1500	0.7 w 0.4 vw
				0.1 st 0.4 yg		1.7 vw		
Minn. No. 90	1/40 A.	Trace yg	3701	0.03 w 0.03 vw 0.3 yg	1911	0.4 yg	1400	None
Minn. No. 91	3126	1.2 w	3582	0.8 w 0.2 yg	1590	0.8 w	1170	0.4 w
Minn. No. 92	3523	2.7 w	4120	2.6 w	1737	1.1 w	1455	1.0 w
Minn. No. 2	2511	0.04 w	2112	0.05 w 0.05 vw	2527	None	1700	None
Recomb. AA of 8 selfed strains					642	None	1600	None

* w = white seedlings.
yg = yellow-green seedlings. (The type of p'ant produced by these seedlings was not determined in each case.)
st = striped seedlings.
cyl = seedlings with a cylindrical first leaf.
vw = virescent white seedling and plant.

A reduction in yielding ability has been obtained for most of the selection strains, as determined by rod-row studies; a few strains, on the other hand, appear very promising in this respect in relation to normal Minn. No. 2.

The studies of self-fertilization were begun in 1920, the selfings that year being made in the above mentioned selection strains.

INBREEDING THROUGH SELF-FERTILIZATION

The use of artificial self-pollination in cross-fertilized crops as a means of reducing heterozygous material to pure lines is a relatively new method. It is being applied extensively in corn breeding work in the United States and Canada, and to a lesser extent with timothy, sunflowers, red clover, and many other crops that are naturally cross-pollinated, as well as for certain clonally propagated crops such as potatoes. Its successful application to any particular crop depends to a considerable extent upon the ability of individual plants to set sufficient seed under artificially self-pollinated conditions to carry the strains year after year. Corn is nearly, if not entirely, self-fertile. Red clover and sunflowers were formerly considered to be completely self-sterile, but Fergus (6) obtained considerable seed setting in self-pollinated red clover; and McRostie (20) and Hamilton (9) have shown that artificial self-pollination is a practical means of isolating pure breeding strains of sunflowers. That selfed strains of timothy differ in their ability to produce selfed seed, some appearing highly self-fertile and others largely self-sterile, has been determined by Hayes and Clarke (13). It has long been recognized that a high degree of self-sterility is characteristic of rye.

The extent to which vigor and yielding ability are reduced as a result of self-fertilization is of great importance. Formerly it was believed that continued self-fertilization in cross-fertilized crops would lead to a continuous reduction in vigor. It has been shown in recent years, particularly for corn, that such is not the case, but that after homozygosity is reached there is no further reduction in vigor.

EARLY STUDIES OF SELF-FERTILIZATION IN RYE

Most of the early work with self-fertilization in rye was done by German and Swedish plant breeders. Rimpau (Ulrich 30) was the first to attempt a solution of the question concerning the self-fertility of this plant. By the use of parchment bags he obtained an average seed setting of 1.1 per cent for spikes bagged singly, and 1.7 per cent for two spikes of the same plant bagged together; and with glass tubes 0 9 per cent and 4.4 per cent, respectively, for the same methods. He

concludes that self-sterility is not absolute in rye, but that self-fertility is very limited.

Ulrich studied the comparative self-fertility of three varieties of rye, Petkuser, Probsteier, and Schlanstedter. Parchment bags were used to cover the spikes. The results are summarized in Table II.

TABLE II

COMPARISON OF PERCENTAGE SEED SETTING BY SELF-FERTILIZATION, USING PARCHMENT BAGS AS AN ISOLATION AGENT

Variety	Single spike selfed	Two or more spikes bagged together		Normal pollination
		Single plant	Different plants	
Petkuser	1.30	2.52	28.29	80.0
Probsteier	2.33	4.98	25.12	59.0
Schlanstedter	5.02	7.31	38.32	78.0

In another experiment, using two varieties of rye, Schlanstedter and Zwätzener, glass test tubes and parchment bags were compared as isolation agents. When the bags were used, one was shoved inside the other as a better protection against stormy weather. The results obtained are presented in Table III.

TABLE III

COMPARISON OF PERCENTAGE SEED SETTING BY SELF-FERTILIZATION FOR SCHLANSTEDTER RYE AND ZWATZENER RYE, USING BOTH PARCHMENT BAGS AND GLASS TUBES AS ISOLATION AGENTS

Variety	Isolation agent	Year	Single spike selfed	Two or more spikes bagged together		Normal pollination
				Single plant	Different plants	
Schlanstedter	P.B.	1877	1.10	1.90	23.40	77.30
Schlanstedter	G.T.	1881	0.90	4.40	26.20	
Schlanstedter	P.B.	1900	5.02	7.21	38.32	78.00
Zwätzener	P.B.	1900	8.26	7.79		82.53
Zwätzener	G.T.	1900	0.96	0.60	22.92	82.53

Ulrich concluded from these and other experiments that there are individual differences within a race, both fully sterile and strongly self-fertile individuals being found.

Obermayer (22) performed two small experiments with rye, in one of which he removed all but the central florets and artificially selfed those, and in the other he used the ordinary method of bagging a single spike. An average percentage seed setting of 3.2 was obtained by the first method for 7 hand-pollinated spikes and 8.8 per cent by the latter method for 8 spikes bagged. In another experiment, in 1911-12, plants were enclosed in large isolation cages, but no seeds were obtained. He concludes that varieties and plants within a variety differ in self-fertility.

The work of N. Heribert-Nilsson (14, 15, 16) is the most extensive of its kind reported. He found that linen as employed by Giltay is not

a sure isolation agent, as it has too large a mesh; that parchment bags are ideal if they can be protected from wind and rain; and that glass test tubes are not so good as parchment bags because they constitute a hindrance to transpiration but that they will serve the purpose where parchment can not be used. Heribert-Nilsson used three principal methods of isolation, namely, (1) glass test tubes; (2) isolation by space, i.e., single plants were separated 50 meters apart in wheat fields; and (3) parchment bags. As an average of 356 plants isolated, he found the seed setting to be about 1, 7, and 4 per cent, respectively, for the three methods. Seed setting for most plants ranged from 0 to 5 per cent with one or two in every 100 plants showing a high degree of self-fertility. Most of these highly self-fertile plants produced very poor seed, and in a mixed stock would tend to be eliminated. In 1921, strains were being carried that had been continuously inbred by self-fertilization for nine generations. There was, in general, a decrease in vigor due to inbreeding, but since the fifth generation there has been no further decrease in vigor. A few strains which had been selfed for several generations continued vigorous and yielded more than the normal variety. When the better inbred lines were again crossed, it was possible to obtain increased vigor, and new varieties were produced which showed improvement over the old. The variety "Stormrag," a rather short, stiff-strawed variety with compact spikes, was produced by crossing inbred strains of Petkuser.

STUDIES OF SEED SETTING WITHIN A SINGLE FLORET AND BETWEEN NEARBY FLORETS ON THE SAME HEAD

Rimpau, in 1876 (Ulrich, 30) wrapped thread about each of four spikes of rye with complete barrenness as a result. Ulrich covered spikes of rye with cotton wadding tied with raffia. He did not obtain any selfed seeds and he concludes, as did Rimpau, that "the rye flower is self-sterile," but he believed also that "self-fertilization within a spikelet is possible." Fruwirth (7) reached a similar conclusion regarding the lack of fertility within a single flower.

Heribert-Nilsson (14) considered these experiments untrustworthy, for he says "flowers which can not open form no seeds," but he did not substantiate his criticism with experimental data.

An investigation was undertaken by the writer in 1922 for the purpose of bringing more evidence to bear upon the question of single floret and single spikelet fertility. All the spikelets but one were removed from some of the spikes, while a single floret was left on others. Some of the single florets were artificially self-pollinated. A floret was chosen which showed signs of immediate anthesis and all others were removed from the spike. The anthers were then removed with

forceps and the stigma was dusted well with pollen, assuring self-pollination. After each pollination the forceps and scissors were dipped in alcohol, and all spikes manipulated were covered with glassine bags. From the 64 single florets which were hand-pollinated, 3 seeds were obtained (Table IV). This indicated the probability that a single floret was sometimes self-fertile, altho it was recognized that accidental cross-pollination may have occurred.

TABLE IV

RESULTS OBTAINED IN A DETERMINATION OF SEED SETTING WITHIN A SINGLE FLORET AND A SINGLE SPIKELET

Variety	Type of manipulation	Single floret		Single spikelet		
		No. of heads bagged	No. of seeds	No. of heads bagged	No. with one floret fertile	No. with both florets fertile
Results obtained in 1922						
Minn. No. 2	Bagged, untreated	35	0	34	7	4
Minn. No. 2	Selfed by hand.....	64	3	..	..	..
Minn. No. 2	One floret selfed by hand, other floret untreated..	..	..	12	0	3
Prolific Spring	Bagged, untreated	41	0	18	0	0
Results obtained in 1923						
Minn. No. 92	Bagged, untreated	35	0	34	4	0
Minn. No. 92	Not bagged, check.....	12	11	13	6	1
Minn. No. 91	Bagged, untreated	24	0	13	1	0
Minn. No. 91	Not bagged, check.....	12	2	5	0	1
Minn. No. 92	One floret emasculated....	..	..	6	0	0
Minn. No. 91	One floret emasculated....	..	..	19	1*	0
Minn. No. 91	One floret emasculated, not bagged, check	..	..	7	1* 2†	4

* Floret emasculated.

† Floret not emasculated.

In 1923 further results were obtained (Table IV). In some of the single spikelets, one floret was emasculated while the other was left intact. On 26 spikelets so treated 4 seeds were obtained, 2 in emasculated florets, and 2 in florets in which the anthers were left.

A slightly different method was used for part of the studies in 1923 and all of the studies in 1924 and 1925. All spikelets were removed from the head except two, the one located just above the other. Sometimes one or two spikelets were removed between the two. The central floret was plucked from the remaining spikelets. The left- and right-hand florets of the upper spikelets were designated as "a" and "b," and those of the lower spikelet as "c" and "d," respectively. The "b," "c," and "d" florets were emasculated when the anthers were still green but "a" retained its anthers. The data obtained by this method in 1923-25 are presented in Table V. In a total of 392 spikes treated in this way and bagged, 31 seeds were produced in the "a" florets, 26 in the "b" florets, and 34 in the "c" and "d" florets of the lower spikelet. In 1924 the awns were clipped close to the lemma on several of the

manipulated spikes. On several spikes the bags were rolled somewhat tightly about the head. Neither of these treatments seemed to influence the degree of seed setting. Under the conditions of this experiment there appears to be no physiological difference in fertilization within a single floret or between different florets on the same head. The fact that seed setting was very limited when pollination was done artificially shows that the apparent self-sterility is not a result of lack of pollination but is probably largely genetic in nature. The difference in seed setting between the lower and the upper spikelets is believed to be due to a difference in pollination, since it is probable that the bag would induce a greater degree of self-pollination than is obtained under open-pollinated conditions.

TABLE V

RESULTS OBTAINED IN AN EXPERIMENT TO DETERMINE WHETHER POLLEN FROM AN INDIVIDUAL FLORET WOULD FERTILIZE THAT FLORET AS READILY AS OTHER FLORETS IN THE SAME SPIKE

Variety	No. of heads bagged	Total No. of florets	Total No. of seed			Per cent of seed setting			Mean per cent seed setting
			a floret	b floret	c & d florets	a floret	b floret	c & d florets	
Results obtained in 1923									
Minn. No. 92.....	8	32	0	0	1	0	0	6.3	3.1
Minn. No. 91.....	40	160	1	0	0	2.5	0	0	0.6
Results obtained in 1924									
Minn. No. 90.....	49	196	3	2	1	6.1	4.1	1.0	3.1
Minn. No. 90.....	48	192	4	3	1	8.3	6.3	1.0	4.2*
Minn. No. 92.....	56	224	0	3	1	0	5.4	0.9	1.8
Minn. No. 92.....	29	116	1	3	7	3.4	10.3	12.1	9.5*
Results obtained in 1925									
Minn. No. 92.....	71	284	8	6	8	11.3	8.5	5.6	7.7
Minn. No. 92.....	43	172	5	5	11	11.6	11.6	12.8	12.2*
Minn. No. 91.....	20	80	2	0	0	10.0	0	0	2.5
Cult. R63†	11	44	2	1	0	18.2	9.1	0	6.8
Cult. R99†	7	28	0	0	0	0	0	0	0
Cult. R105†	2	8	1	1	1	50.0	50.0	25.0	37.5
Cult. R87†	8	32	4	2	3	50.0	25.0	18.8	28.1
Total.....	392	1568	31	26	34				
Mean per cent seed setting			7.9	6.6	4.3				

* Bags were found to be slightly damaged at harvest.
† Highly self-fertile strain.

To determine if flowers that were prevented from opening would set seed, several spikes of Minturki winter wheat and Velvet barley were wrapped tightly, some with cloth tape and others with strings. A very good seed setting was obtained under these conditions, altho it was not normal (see Table VI).

TABLE VI

RESULTS OF A STUDY OF WRAPPING MINTURKI WINTER WHEAT AND VELVET BARLEY SPIKES TO DETERMINE WHETHER OPENING OF THE FLOWER IS ESSENTIAL FOR SEED PRODUCTION

Head No.	Wrapping material used	No. of florets wrapped	No. of seed set	No. of florets unwrapped	No. of seed set
Results with Wheat					
1	Cloth tape	20	11	12	12
2	do	14	7	16	15
3	do	26	21	..	..
4	String	30	17	..	..
5	do	34	23	..	..
*Results with Barley**					
1	Cloth tape	20	19	10	6
2	do	20	0	10	0
3	do	20	20	..	..
4	do	22	15	6	3
5	String	26	6	12	12
6	do	10	0	14	2

* Only lateral florets were counted.

In consideration of the fact that in the barley variety used in this experiment the anthers may often be found dried up at the end of the mature kernel, and that, furthermore, fertilization commonly takes place before the spike is out of the leaf sheath, it appears probable that opening of the floret does not necessarily accompany the flowering stage.

METHOD USED AND RESULTS OBTAINED FROM SELF-FERTILIZATION IN MINN. NO. 2 RYE

The first selfings were made in 1920 but the data for that year were not extensive and have not been included in the material herein presented.

Good quality glassine bags were used almost entirely previous to 1925. These bags were very light in weight and consequently it was not necessary to tie the bagged plants to stakes. As a protection against storms, which are very common at this time of year, a muslin cage (Fig. 2) was placed around the selfing plot just previous to flowering time. In spite of this, heavy storms occasionally caused considerable damage to the glassine bags. Extreme care was taken at these times, as long as flowering continued, either to replace torn bags with new ones, if the work was done immediately following the storm before any pollen was in the air, or to discard the spikes when there was danger of off-pollination. Obviously, in very unfavorable years, particularly when as many as three severe storms came within the flowering period in a single year, it is possible that, with the closest inspection, some slightly damaged bags may have escaped attention. In 1925 a vegetable parchment bag which was glued with a casein waterproof glue was used for rye pollination. After having gone through several storms

every bag was perfect at harvest time. These bags were much larger and heavier than the glassine bags and the bagged plants were tied to stakes (Fig. 3). In previous years usually only one or two spikes were enclosed in a single bag, while in 1925 as many as 10 to 12 spikes on one plant were bagged together, with very satisfactory results.



Fig. 2. Plot in Which the Artificial Self-Pollination Studies Were Made in 1922 Glassine Bags Were Used in These Studies
Upper, Selfing plot enclosed in a muslin cage as protection against strong winds. Lower, Selfing plot with heads bagged before muslin was put up.

Occurrence of abnormalities.—Chlorophyll deficiencies appear to be one of the most common types of abnormalities observed in many crops. White seedlings have been found in many selfed strains of rye. Similar characters have been reported in corn by Lindstrom (18, 19), Hutchison (17), Hayes and Brewbaker (12), and others; in timothy by Hayes and Barker (11); in red clover by Fergus (6); in sorghum by Conner and Karper (2); and in barley by Hallquist (8).

Many other types of chlorophyll deficiencies characteristic of seedlings and plants have been observed by these and other investigators, particularly in connection with inbreeding studies in heterozygous plant material. Practically all chlorophyll deficiencies reported appear to be recessive, and plants exhibiting those characters are either lethal or at least much less vigorous than the normal green plants. White seedlings and other lethal or semi-lethal types tend to be eliminated from heterozygous cross-pollinated stock. This fact has been well demonstrated in an investigation reported by Heribert-Nilsson (15) in which a cross was made between a wax-free recessive character and normal plants and the progeny carried as a bulk in an isolated plot for six generations. Each year the wax-free plants were removed before flowering. As a result the relative proportion of gametes and plants of the normal and wax-free types, in each generation beginning with F_2, could be determined from the following formulas:

$$n:1 = \text{gametic ratio}$$
$$n^2-1:1 = \text{phenotypic ratio}$$

when n = filial generation following the cross, while the first and last terms of the ratio represent normal and wax-free gametes and plants, respectively. Thus, in the F_6 generation the gametic ratio of any pair of factors would be 6:1 and the pheno-typic ratio 35:1. The results obtained by Heribert-Nilsson agree very well with the expectation on this basis.



Fig. 3. Encaged Selfing Plot in 1925

Vegetable parchment bags were used as isolation agents and the plants were tied to stakes for protection from storms. As many as 10 or 12 spikes on one plant were frequently enclosed in a single bag.

The theoretically expected percentage of abnormal types may be obtained likewise by the use of a formula presented by Emerson (5) as follows:

$$F_n = \frac{100}{(n-1)^2 + 2(n-1) + 1} = \text{per cent of abnormal plants in } F_n \text{ generation.}$$

This formula reduced to its lowest terms becomes $F_n = \frac{100}{n^2}$

A survey of the rye varieties included in the varietal test at University Farm in the fall of 1924 revealed the fact that white seedlings were segregating out from each of the varieties except Minnesota No. 90, one of the selection strains previously referred to; while other chlorophyll deficient types were of less frequent occurrence in most of the strains (see Table VII). The data for the occurrence of similar abnormalities in the selection strains have been summarized in Table I. Elimination of these and other seedling and plant abnormalities appears to be an important feature in rye breeding, and while individual plant selection with progeny isolation will accomplish this purpose more rapidly than mass selection, neither method can be considered very efficient for this purpose.

TABLE VII

Occurrence of Seedling Abnormalities in Commercial Rye Varieties
One-Fortieth Acre Plots, 1924

Variety	Total seedlings	Seedling abnormalities*			
		w	vw	yg	st
Petkuser	23,200	5	2	..	..
Midsommerog	36,170	6	6	..	..
Colorless, Minn. No. 90	30,400	..	..	46	1
Medium Green, Minn. No. 91	17,440	120	1	20	..
Dark Green, Minn. No. 92	31,680	236	..	..	..
Swedish, Minn. No. 2	34,400	3	1	1	..
Rosen	21,120	2	..	1	..
Dakold	23,200	13	..	1	..

* w = white. yg = yellow-green.
vw = virescent white. st = striped.

Through the isolation of self-fertilized lines, recessive abnormalities can be quickly eliminated. There has been no particular selection for freedom from abnormalities in any of the selfed strains. The progenies each year were not large, consisting of perhaps 12 to 15 plants on the average and varying from 1 to 30 plants, depending upon the selfed seed available for planting. It is to be expected that small progenies may apparently be normal under those conditions, but still carry the recessive factor for some abnormality in the heterozygous condition. Of 31 strains which have been continuously self-fertilized since 1922, 8 appeared to be free from chlorophyll deficiencies throughout the four

years. Twelve other strains which segregated in 1922 appeared normal for both 1924 and 1925. The apparent complete freedom of some strains and the reduction of segregating strains to purity for normal plants are indications of the effects of self-fertilization.

A chlorophyll-deficient seedling and plant character which has been fairly common in occurrence in the inbred strains has been designated as "yellow-green stripe." There appears to be considerable variation in the character from almost pure yellow plants striped with green to almost pure green plants striped with yellow. The parental strains studied in 1922 and 1923 segregated for 65 normals and 20 yellow-green stripes. Crosses were made in 1923, and the F_1 in 1924 was backcrossed to yellow-green stripe with the following results:

Backcross culture numbers	Normal	yg stripe
R 94 b × R 35 yg stripe	10	7
R 94 × do do	17	14
R 94 c × do do	33	34
R 95 b × do do	25	21
Observed total	85	78
Calculated (1:1 ratio)	81.5	81.5
P. E.	3.73	

From these results it appears that the yellow-green stripe character is a simple recessive to normal green.

What appeared to be a "yellow-green stripe" bud variation was observed on a plant obtained in one of the selfed lines. This plant had 17 normal green culms and only 1 striped culm, the latter being very much reduced in vigor. The spike on this single culm was bagged but no seeds were obtained.

Another chlorophyll deficient type observable in both seedlings and plants has been called "golden-green blend." In contrast to the yellow-green stripe, it has a much deeper yellowish color, is very uniform in its expression, and while there is a tendency to striping, the stripes of green and yellow are blended together. It is less vigorous than normal plants, and it appears to be much less common in occurrence than the yellow-green stripe. In 1923 a cross was made of a golden-green blend plant in selection culture 901 with a normal green plant in a pure green selfed strain, and in 1924 the F_1 was backcrossed to a golden-green blend plant. Only 21 seeds were obtained, and the resulting progeny consisted of 10 normal and 11 golden-green blend plants. While these data are very limited, they indicate that this character is probably inherited as a simple recessive.

Virescent-white seedlings, somewhat similar to those reported in maize (Lindstrom, 18), have been found about as frequently as golden-green blend plants. They appear to be fairly vigorous, altho not approaching the normal condition in this respect. A virescent plant in

the 1923 selection culture No. 1501 was crossed with a normal green plant. In the F_2 generation from this cross there were 107 normal to 35 virescent-white seedlings. This closely approaches a 3:1 ratio, and it may be concluded that the character behaves as a simple recessive to normal green.

Another seedling abnormality, called "cylindrical" because of the cylinder or tube-like nature of the first leaf, has been obtained in two cultures. It is of considerable interest because of its similarity to a character now being studied in maize.



Fig. 4. Stubble of Brittle Plants as Commonly Broken Off by the Wind

So-called "brittle" plants have been observed in a number of selfed lines. Such plants may often be recognized in the field (Fig. 4), particularly after a storm, by the broken stubble where the culm has broken off completely. A chemical analysis as well as a histological and microchemical examination (Davison, Brewbaker, and Thompson, 3), shows that these brittle plants have a much thinner cell wall, a lower crude fiber, a higher pentosan content, and considerably less lignin than the normal plants. Because of the very weak, brittle nature of the straw, it is difficult to obtain selfed seed by bagging. A hand-pollinated cross of two brittle plants gave 42 brittle plants in 1925. The character

was observed in 16 selfed lines during 1922, 1924, and 1925; and in these lines there were 158 normal to 56 brittle plants. The ratio expected on the basis of a single factor difference would be 183 normal to 61 brittle, the difference being well within the range of probability.

Other abnormalities, among which might be mentioned crinkled awns and pollen sterility, have been observed in the inbred strains. Pollen sterility was found in one strain segregating with plants which were apparently self-fertile to a fairly high degree. In a total of 35 plants obtained, 19 had defective pollen and did not set seed when bagged, 9 gave less than 8 per cent seed-setting, and 7 set seed in from 14.7 to 34.5 per cent of the florets.

Seed-setting ability in relation to self-fertilization.—A high degree of self-sterility has been characteristic of the majority of the inbred plants. Individual plants giving a high percentage of seed setting have been obtained each year and certain strains appear to be more or less uniform for this character, altho the greater part of the data obtained show much variability from year to year. The average percentage of seed setting obtained for the selfed strains during the years 1921 to 1925 is presented in a summary table (Table XIII, Appendix). A study of this table reveals many cases of apparently highly self-fertile individual plants having produced strains of low average fertility, and vice versa. A more detailed study of three lines selfed for five successive generations and having a common origin in 1920 is given in Table VIII. The first strain appears to be pure for relatively high self-fertility in 1924 and 1925; the second strain is segregating; and the third strain seems to be pure for fairly low self-fertility, altho the progenitor of this line in 1921 gave the highest percentage seed setting of any plant in the strain.

Throughout the course of these investigations there has been a rather consistent selection of plants which set the highest percentage of seeds, other things being equal. The effects of this selection are well brought out in Table IX, which summarizes the percentage seed setting in 1925 for strains that have been selfed the same number of years. There is a gradual increase in mean percentage seed setting from 3.1 for lines selfed one year to 14.1 for lines selfed 4 years, then dropping back to 7.7 for 5-year selfed lines. This is a further indication that the character of self-fertility is a heritable one.

TABLE VIII

PEDIGREE OF THREE SELF-FERTILIZED LINES HAVING A COMMON ORIGIN IN 1920, WITH PERCENTAGE SEED SETTING FOR THE PLANTS OBTAINED EACH YEAR

1921		1922		1923		1924		1925	
Plant No.*	Percentage seed setting	Plant No.	Percentage seed setting	Plant No.	Percentage seed setting	Plant No.	Percentage seed setting	Plant No.	Percentage seed setting
5—12	1.7	1—3	35.1	3—5	51.1	32—3	50.9	69—1	19.9
—18	1.6	—1	67.6	—1	0	—1	50.7	—2	41.3
—22	1.6			—4	4.3	—2	40.5		
—25	1.3			—6	0	—4	10.4		
—30	2.9			—7	0	—5	23.8		
—35	3.3								
—42	5.9								
—43a	1.5								
—48	1.5								
—39	9.4	2—4	12.5	4—10	7.5	31—4	76.8	67—1	0
—49	9.7	—2	5.0	—1	1.6	—1	0.8	—2	69.0
		—3	1.1	—3	0	—2	64.4	—3	34.0
		—5	0.5	—4	0	—3	0	—4	52.4
		—6	0	—5	0.7	—5	14.3	—5	1.4
		—8	2.8	—7	0	—6	1.0		
		—9	6.3	—8	0	—7	37.5		
		—10	0	—9	0.8	—8	13.0		
				—11	0.8	—9	3.0		
				—12	14.3	—10	0		
						—11	4.2		
—45	19.7	3—11	10.9	6—3	19.5	35—3	2.7	73—1	0.6
		—1	9.4	—1	2.2	—1	10.8	—2	0.3
		—6	0	—2	0.5	—2	4.2	—3	3.4
		—7	0	—4	0	—4	3.4	—4	10.9
		—8	0	—5	0	—5	3.3		
		—9	0	—7	0	—6	0.6		
		—10	0.4	—8	0.4	—7	1.7		
				—9	0.4	—8	6.3		
						—9	2.8		
						—10	0.9		
						—11	7.6		

* The underscored plant numbers are the parents for the succeeding strain. In 1921, seed from nine plants was bulked for planting in the first strain and seed from two plants for the second strain.

TABLE IX

PERCENTAGE SEED-SETTING FOR SELFED LINES IN 1925

No. of years selfed	Classes for percentage seed-setting																			Total	Mean
	2	5	8	11	14	17	20	23	26	29	32	35	38	41	44	47	50	53			
1	21	11	3	1																36	3.1
2	5	2						1												8	4.7
3	7	2	2				1											1		14	9.1
4	4	3	2	1	1	1	1		2	1	2	1								19	14.1
5	2	3	2	3	1			1												12	7.7

While there appears to be no doubt as to the heritability of the characters of high and low self-fertility, the fact remains that there is considerable variability in the degree of fertility in one year as compared with another. A correlation of the percentage seed setting in

1925 of 45 strains which had been selfed 3, 4, or 5 years with the percentage seed setting of the same strains for 1924 gives a correlation coefficient of 0.2044 ± 0.0963. Somewhat similar results were obtained by Heribert-Nilsson (14) in a comparison of two consecutive years' results. The writer studied Heribert-Nilsson's data by computing a correlation coefficient for percentage seed setting of 42 strains in consecutive years. The calculated coefficient was 0.1709 ± 0.1010. Heribert-Nilsson considers the character of high self-fertility to be a simple recessive. In that case highly self-fertile plants should produce uniformly highly self-fertile progenies. As has already been pointed out, such results have not always been obtained in these studies. Part of the variability in the degree of seed setting in certain strains year after year is without doubt due to the small number of plants available for selfing; thus, the mean percentage of seed setting for the strain may not always be a true mean of the genetic variation in this respect. It is true, also, that the degree of seed setting varies considerably with the year, e.g., in 1921 the average percentage fertility for single heads, two heads bagged together, and sibs was 1.7, 2.2, and 14.2; while in 1922 the average results for the same three methods were 10.6, 13.5, and 41.1, respectively. Climatic conditions during the period of flowering may cause fluctuations which prevent the expression of heritable differences.

Furthermore, it is possible that the environmental conditions under the bag may influence the degree of seed setting to a greater extent for some strains than for others. Certain unpublished data which appear pertinent in this connection have been furnished by Dr. H. K. Hayes. The percentage barrenness was determined for covered heads in relation to uncovered heads in Marquis and Mindum wheat and in Emmer. The results obtained are presented in Table X.

TABLE X

Comparison of Effect of Covering Heads with Bags Upon Degree of Seed Setting

Variety	Uncovered		Covered		Difference in mean per cent barrenness for uncovered and covered heads
	No. of plants in trial	Mean per cent barrenness	No. of plants in trial	Mean per cent barrenness	
Marquis	30	16.6	30	31.3	14.7
Mindum	16	14.4	10	46.4	32.0
Emmer	33	3.7	29	47.9	44.2

Covering the heads with a bag increased the mean percentage barrenness 14.7 for Marquis, 32.0 for Mindum, and 44.2 for Emmer. Such a differential effect may account to some extent for the variability in percentage seed setting for the selfed strains of rye in consecutive years.

Resistance to Puccinia graminis secalis.—The seedlings of selfed lines and normal varieties were tested for their reaction to *P. graminis secalis* during the winter of 1922-23. The readings were based upon the scale devised by Stakman and Levine (27) using "0" to "4" classes; "0" standing for complete immunity or non-infection, and "4" standing for complete susceptibility. (Note Figs. 5 and 6.)

Conditions in the greenhouse were not always the most favorable for rust development, hence it seems probable that most, if not all, of the plants classed as "0" should not be considered immune, but merely as having escaped infection. Such a condition is certainly true in the case of certain cultures which on first test gave "0" infection and on second test proved susceptible.

Not a single strain was tested, however, which appeared uniform for resistance. Recent work of Mains (21) indicates that resistance to black stem rust, as well as to leaf rust and mildew, is dominant to susceptibility. The fact that a condition of homozygosity for resistance to black stem rust was not noted in these studies would not be unexpected, since only 39 strains, none of which had been selfed for more than three generations, were tested. Certain it is, however, that individual plants in Minn. No. 2 and in many of the selfed strains proved to be highly resistant.

Uniformity and relative vigor of selfed lines.—The tendency toward homozygosity for rust reaction has already been mentioned. A number of strains are free from striking abnormalities. Evidences of uniformity for other characters have also been observed. The 3-year selfed progeny of plant R14-3 appeared uniform for size and general plant characteristics (Figs. 7 and 8) and the grain was uniformly green in color. A marked reduction in vigor as indicated by plant growth is also noted.

Many of the selfed strains are pure for aleurone color. Lack of color is recessive in inheritance to the presence of green or blue in the aleurone layer (Steglich and Pieper, 28; Treboux, 29). Treboux points out, however, that grains which appear colorless to the eye will sometimes give color in the progeny, and that the presence of a small amount of color in the aleurone layer may be masked by a thick seed coat. This has been noted also in connection with the Minnesota studies.

In general, the vigor and yielding ability of the self-fertilized strains are somewhat reduced, altho a few outstanding long-time selfed strains continue to be vigorous. One such vigorous 3-year selfed strain is shown in Figure 9 in relation to a very weak, altho uniform, sister strain, and a check row of Minn. No. 2.



Fig. 5. Types of Reaction of Minn. No. 2 Rye to *P. graminis secalis* Ranging from "4" Infection at Left to "0" Fleck at Right

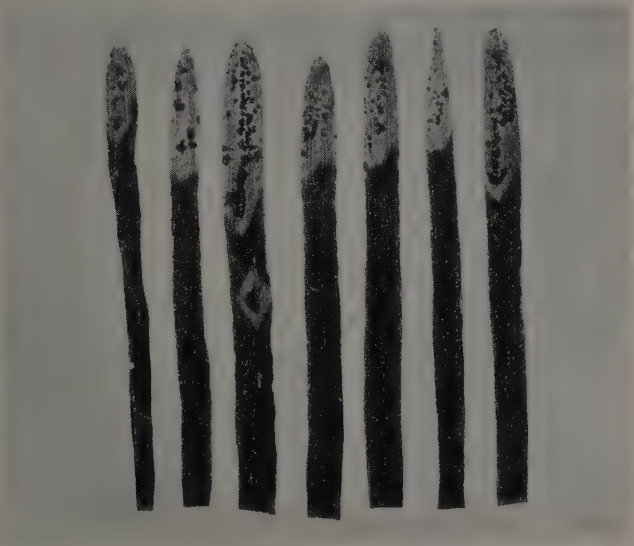


Fig. 6. A Homozygous Susceptible Strain
Reaction of Culture R20-13 to *P. graminis secalis*. Appears homozygous for "3" to "4" Infection.

A preliminary yield test of the selfed strains, when seed was available, has been conducted for three consecutive years, 1923-25. Twenty seeds of each strain were planted in 5-foot rows (see Fig. 9). Replication was not practiced because of the small amount of seed usually available. Normal Minn. No. 2 was planted in every sixth row as a check. The yield and height data are included in Table XIV, Appendix. The average yield, in grams, for the check rows was considered as 100, and the yields of the selfed strains were calculated in percentages of the check. The percentage yields have been grouped

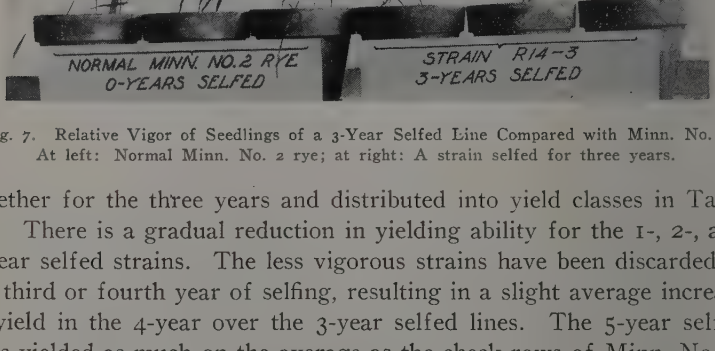


Fig. 7. Relative Vigor of Seedlings of a 3-Year Selfed Line Compared with Minn. No. 2 At left: Normal Minn. No. 2 rye; at right: A strain selfed for three years.

together for the three years and distributed into yield classes in Table XI. There is a gradual reduction in yielding ability for the 1-, 2-, and 3-year selfed strains. The less vigorous strains have been discarded in the third or fourth year of selfing, resulting in a slight average increase in yield in the 4-year over the 3-year selfed lines. The 5-year selfed lines yielded as much on the average as the check rows of Minn. No. 2. In comparison with the results obtained for corn, the reduction in vigor and yielding ability in rye appears to be much less. In this respect the results obtained for rye are similar to those obtained for timothy (13) and for sunflowers (9, 20).

TABLE XI
COMPARISON OF PERCENTAGE YIELDS OF SELFED STRAINS IN RELATION TO THE MEAN OF THE CHECKS

	Percentage yield classes																	No. of tests	Mean per cent	
	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155	165	175		
Individual checks (1923)						1	1	1	2	2	3	4	2						16	100
Individual checks (1924)							2	1	3		4	2		2					14	100
Individual checks (1925)					2		1			4	2			1	1	1			12	100
1 yr. selfed (1923, 1924, 1925)				2	1	5	1	4	3	3	1	2		1					23	74.4
2 yr. selfed (1923, 1924, 1925)	3	2	2	1	1	2	6	4	2	4		2	1						30	63.4
3 yr. selfed (1923, 1924, 1925)	2	6	5	2	4	2	3	1	4		4		2	1					36	56.2
4 yr. selfed (1923, 1924, 1925)		3	5	4	3	1	2		2		3		1	1				1	26	59.5
5 yr. selfed (1923, 1924, 1925)				1	2						1	1			1	2			8	100.5

A correlation study of the percentage yielding ability of thirty-eight 3-, 4-, and 5-year selfed lines for two successive years gives a correlation coefficient of 0.0716 ± 0.1614. As the yield test was necessarily conducted on a very small scale and without replication to overcome the effects of soil heterogeneity, it is evident that under these conditions a correlation coefficient does not well express the inheritance of such a variable character as yielding ability. Certain outstanding cases of uniformly vigorous high-yielding strains in contrast to others which are uniformly reduced in vigor, as, for example, those shown in Figure 9 (cultures 55 and 44, respectively, in Table XIV, Appendix), lead to the conclusion that the character of vigor and yielding ability is very definitely inherited, and that homozygous selfed strains may be obtained which are equal to or even surpass the normal variety in this respect.



Fig. 8. Comparison of Height of Mature Plants Resulting from Seedlings Shown in Fig. 7
At left: Three pots of normal Minn. No. 2; at right: Three pots of strain R14-3, 3 years selfed. Note uniformity of R14-3.

The 1-year selfed lines appeared to be about equal in height to the normal checks (Table XII), while the 2-, 3-, and 4-year selfed lines showed a gradual reduction as a result of approaching homozygosis due to selfing. A correlation study similar to that made for yield for the same 38 strains gave a coefficient of 0.4450 ± 0.0855, indicating fairly consistent differences in height one year with another.

TABLE XII

COMPARISON OF PERCENTAGE HEIGHT OF SELFED STRAINS IN RELATION TO THE MEAN OF THE CHECKS

	Percentage height classes													No. of tests	Mean pr.cent height
	58	63	68	73	78	83	88	93	98	103	108	113	118		
Individual checks (1923)								2	8	4	2			16	100
Individual checks (1924)								3	4	6	1			14	100
Individual checks (1925)							1	1	8		1		1	12	100
1 yr. selfed (1923, 1924, 1925)							2	2	6	7	2	2	2	23	101.5
2 yr. selfed (1923, 1924, 1925)	1				1	3		5	8	5	2	3	1	29	97.4
3 yr. selfed (1923, 1924, 1925)				2	1	4	5	7	8	4	2			23	92.3
4 yr. selfed (1923, 1924, 1925)		1	1	5	1	3	1	8	6	1				27	87.3
5 yr. selfed (1923, 1924, 1925)			1			2	3		3		1			10	90.2

UTILIZATION OF SELFED STRAINS FOR THE PRODUCTION OF IMPROVED VARIETIES

There are many undesirable recessive abnormalities in commercial varieties of rye. These can be eliminated by selection in self-fertilized lines, and uniform strains can be obtained which are as vigorous as the normal variety, or more so. The problem of how best to utilize these desirable strains in the production of improved varieties remains to be solved. There appear to be two possibilities, (1) a single strain may be increased, or (2) two or more strains may be recombined.

There are certain apparent difficulties in the use of a single strain as a basis for a pure line variety. A selfed strain to be of value in this connection must be highly vigorous, produce well-developed kernels of good quality, and be desirable for such other characters as stiffness of straw, winter-hardiness, resistance to disease, and grain color. Besides, it must be highly self-fertile, for in a pure line sib-fertilization is genetically equivalent to self-fertilization; and assuming fertility and sterility to be heritable qualities, as they appear to be, the same degree of sterility would be expected to result from pollinations *inter se* as from self-pollinations. The possibility of obtaining a homozygous strain which combines all of these desirable characters by selfing individual plants and isolating biotypes within a variety appears to be rather remote. On the other hand, it is reasonable to suppose that all of these desirable characteristics could be combined synthetically by crossing

inbred strains, each of which exhibited certain desirable characters which the other lacked, followed by continued self-fertilization and selection for the desirable combinations.



Fig. 9. Comparison Under Field Conditions of Selfed Strains and Minn. No. 2
At left: Minn. No. 2; in center: A vigorous 3-year selfed strain; at right: A weak 3-year selfed strain. The selfed strains are progenies of sister plants. Photo, 1923.

The second method for utilizing selfed strains in the production of improved varieties involves the recombination of two or more lines. The first crosses of two or more lines may be made artificially and random mating allowed for several years in an isolated plot. Very much the same results may be obtained by mixing seed of the strains to be recombined and planting in an isolated plot. In this kind of planting there may be some self-pollination and sib-pollination between plants of the same original inbred strains, but individuals resulting from such pollinations would decrease rapidly in succeeding generations. After several years approximately the same recombined variety will be obtained as if the crosses were made artificially. Hybrid vigor will be expected in the first-generation cross of inbred lines which contain different important growth factors, and some decrease in this vigor will be expected in the second generation. Theoretically, the extent to which this decrease in vigor takes place varies indirectly with the number of strains entering into the recombination, altho the relative vigor of the inbred lines as compared with F_1 crosses is a factor of major importance

in this connection. Wright (33) concludes that "a random-bred stock derived from n inbred families will have 1/nth less superiority over its inbred ancestry than the first cross or a random-bred stock from which the inbred families might have been derived without selection."

The choice of strains to use in making recombinations is important. Logically, a uniformly vigorous condition is of prime importance; in this respect, however, strains may supplement each other for different growth factors. Results obtained for corn prove conclusively that strains which are much less vigorous than normal may be recombined and improvement in yielding ability over the original variety obtained (see Hayes, 10). The question of whether a high degree of self-fertility is an essential or desirable characteristic of selfed lines which are to be used in recombinations is difficult to answer. If a variety was produced from strains which were highly self-fertile, it is possible that the percentage of seed setting under field conditions would be increased as compared to normal varieties. On the other hand, if this characteristic resulted in considerable self-fertilization or inbreeding, it is possible that a high degree of self-fertility would be undesirable. To one interested particularly in resistance to disease or other specific characters, the isolation of strains homozygous for the characters in question is of major importance. Under any circumstances, it is desirable to determine how each strain chosen combines or "nicks" with other selected strains. The progeny of a few seed obtained from artificial crosses would probably be sufficient to give this information. Strains which in crosses with other strains produced uniformly vigorous, normal progeny would be used for varietal recombinations.

A somewhat less intensive mode of attack may be of value under conditions where a single character such as color of grain, disease resistance, or winter-hardiness appears of prime importance. Extensive self-fertilizations could be made for perhaps one or two generations, the strains which appeared pure for the desired character selected and an immediate recombination of these strains made.

For the purpose of securing some preliminary information, a mixture of seed from 8 lines which had been selfed for 2, 3, or 4 years, was made. The lines were selected on the basis of desirable field appearance, freedom from striking abnormalities, and plumpness of grain. They were selected as the most desirable from about fifty possible strains, it being appreciated that no information had been obtained as to how each strain would "nick" with each other strain. A few seeds from each strain were bulked and planted in an isolated plot in 1924. Seed harvested from this plot was included in the rod-row yield test in 1925, the yield being 170.5 grams in comparison to 205.5 grams for Minn.

No. 2. As previously stated, a certain amount of self-pollination and sib-pollination has undoubtedly taken place in this mixture of strains, and an accurate determination of yielding ability of the new variety can not be made until a complete random mixture is obtained. This new variety is being carried in an isolated plot each year and its yielding ability will be determined. It is of some interest to note that this variety was free from any striking abnormalities in 1925; and that it appeared to have survived the severe winter of 1925-26 as well as commercial Minn. No. 2 and better than several other varieties in the test.

It is concluded from these studies that the utilization of selfed strains as foundation material for the production of crosses or recombinations is probably the most practical means of improvement in rye.

SUMMARY

1. Continuous selection of single plants of Minnesota No. 2 rye, with distance isolation of the progeny lines, for ten years has resulted in the production of several lines which are highly pure for grain color and relatively pure for certain other characters. Certain of these strains are characterized by the presence of many seedling and plant abnormalities. While there is, in general, a reduction in vigor and yield, certain strains appear promising in comparison with Minn. No. 2.

2. Considerable evidence has been obtained which indicates that there is no consistent difference in degree of seed setting as a result of fertilization within a single floret or between two florets on the same head.

3. The characters of high and low self-fertility appear to be heritable. While the expression of these characters appears to be somewhat variable, certain strains have been isolated which are rather uniformly highly self-fertile in contrast to other strains that are able to set only a few seeds under similar conditions. There has been a conscious selection in these studies for rather highly self-fertile plants. The results of this are reflected in the percentage fertility in 1925 for all strains selfed 1, 2, 3, 4, and 5 years, the mean for these strains being 3.1, 4.7, 9.1, 14.1, and 7.7, respectively.

4. The ability to set seed under controlled conditions appears to be influenced considerably by seasonal conditions. Thus, in 1921, the average percentage seed setting for all selfed strains was 1.7, 2.2, and 14.2 as compared to 10.6, 13.5, and 41.1 in 1922 for single heads bagged, two or more heads on the same plant bagged together, and sib-pollinations, respectively.

5. The high degree of self-sterility in rye is not a serious handicap in the selfing work, as by making sufficient isolations, enough seed of

practically all lines, including the more highly self-fertile ones, can be obtained to continue the strains year after year.

6. Seedling and plant abnormalities are of common occurrence in the selfed lines. White seedlings are the most common type of seedling abnormality. Yellow-green stripe, golden-green blend, and virescent-white types may be recognized in both seedling or plant stages. Inheritance studies of these three characters as well as a brittle plant character indicate each to be a simple recessive to the normal condition. Other types of abnormalities—including seedlings having cylindrical first leaves, plants with crinkled awns, and male or pollen sterility—have been observed.

7. In a test of reaction to *Puccinia graminis secalis,* a number of individual plants in the selfed strains, as well as in the Minn. No. 2 commercial variety, appeared to be highly resistant to the disease. Certain strains were uniformly susceptible, but none of the strains appeared uniformly resistant.

8. Approaching homozygosity in the selfed strains is accompanied generally by a marked reduction in vigor, considerable shrivelling and lack of plumpness in the grain, and some reduction in height of plant, altho in each of these respects individual strains are found which are just as desirable as the parental variety, if not more so.

9. Certain strains appear outstanding in vigor and yielding ability, being equal to or better than Minn. No. 2 in this respect. Some selfed strains are shown to be uniformly vigorous year after year, while others are uniformly stunted and weak. Rye is somewhat similar to timothy and sunflowers in this respect, in contrast to the much greater reduction in vigor in corn as a result of inbreeding.

10. The results obtained in this study, in common with those obtained by Heribert-Nilsson in Sweden, justify the conclusion that the method of breeding rye by selection in self-fertilized lines is not only feasible but is the most effective and practical mode of attack as a means of rye improvement.

LITERATURE CITED

1. Boss, Andrew.
Rye growing in Minnesota. Minn. Agr. Exp. Sta. Bul. 120. (Not available for distribution.) 1910.
2. Conner, A. B., and Karper, R. E.
Chlorophyll deficiencies in sorghum. Jour. Heredity 15:377-378. 1924.
3. Davison, F. R., Brewbaker, H. E., and Thompson, N. A.
Brittle straw and other abnormalities in rye. Jour. Agr. Res. 28:169-172. 1924.
4. Engler-Gilg.
Syllabus der Pflanzenfamilien. pp 128. 1919.

5. Emerson, R. A.
Getting rid of abnormalities in corn. Am. Breeders Assoc. Ann. Rept. 7 and 8:400-404. 1912.
6. Fergus, E. N.
Self-fertility in red clover. Ky. Agr. Exp. Sta. Circ. 29. 1922.
7. Fruwirth, C.
Die Züchtung der landwirtschaftlichen Kulturpflanzen. pp. 187-195. Verlagsbuchhandlung Paul Parey. 1910.
8. Hallquist, Carl.
Gametenelimination bei der Spaltung einer Zwerghaften und Chlorophylldefekten Gerstensippe. Hereditas 4:191-205. 1923.
9. Hamilton, R. I.
Improving sunflowers through inbreeding. Sci. Agr. 6:190-192. 1926.
10. Hayes, H. K.
Present day problems of corn breeding. Jour. Am. Soc. Agron. 18:344-363. 1926.
11. ——— and Barker, H. D.
The effects of self-fertilization in timothy. Jour. Am. Soc. Agron. 14:289-293. 1922.
12. ——— and Brewbaker, H. E.
Frequency of mutations for chlorophyll-deficient seedlings in maize. Jour. Heredity 15:497-502. 1924.
13. ——— and Clarke, S. E.
Selection in self-fertilized lines as a means of improving timothy. Sci. Agr. 5:313-317. 1925.
14. Heribert-Nilsson, N.
Populationsanalysen and Erblichkeitsversuche. Zeitsch. f. Pflanzenzücht. 4:1-44. 1916.
15. ———
Selektive Verschiebung der Gametenfrequenz in einer Kreuzungspopulation von Roggen. Hereditas 2:364-369. See Bot. Abstr. 11. (1922.) 1921.
16. ———
Ragförädlingens Methodik och Principer. Saertryk af Nordisk Jordbrugsforskning. 1919.
17. Hutchison, C. B.
Heritable variations in maize. Jour. Am. Soc. Agron. 14:73-78. 1922
18. Lindstrom, E. W.
Chlorophyll inheritance in maize. N. Y. (Cornell) Agr. Exp. Sta. Mem. 13. 1918.
19. ———
Concerning the inheritance of green and yellow pigments in maize seedlings. Genetics 6:91-110. 1921.
20. McRostie, G. P.
Some forage crop needs and difficulties in Canada. Sci. Agr. 5:97-99. 1924.
21. Mains, E. B.
Rye resistant to leaf rust, stem rust, and powdery mildew. Jour. Agr. Res. 32:201-221. 1926.
22. Obermayer, Ernst
Untersuchungen über das Blühen und die Befruchtung von Winterroggen und Winterweizen. Zeitschr. f. Pflanzenzücht. 4:347-403. 1916.

23. Rümker, K. von
Methode der Pflanzenzüchtung. Verlagsbuchhandlung Paul Parey. Berlin. 1909.

24. ———
Über Roggenzüchtung. Btr. zur Pflanzenzücht. 3:8-28. 1913.

25. ——— und Leidner, R.
Ein Beitrag zur Frage der Inzucht bei Roggen. Zeitschr. f. Pflanzenzücht. 2:427-444. 1914.

26. Schulz, A.
Getreidestudien I. Abstammung und Heimat des Roggens. (Place of origin and descent of cultivated rye.) Ber. Deutsch. Bot. Gesell. 37:528-530. (See Bot. Absts. v. 10, entry 1511, Feb. 1922.) 1919.

27. Stakman, E. C. and Levine, M. N.
The determination of biologic forms of Puccinia graminis on Triticum spp. Minn. Agr. Exp. Sta. Tec. Bul. 8. 1922.

28. Steglich and Pieper, H.
Inheritance and breeding experiments with rye. Fühlings Landw. Ztg., 71:201-221. (For abstract see Exp. Sta. Rec. 48:531.) 1922.

29. Trebaux, O. von
Beobachtungen über Vererbung von Kornfarbe und Anthocyanin beim Roggen. Zeitschr. f. Pflanzenzücht. 10:288-291. 1925.

30. Ulrich, K.
Die Bestaübung und Befruchtung des Roggens. Inaug. Diss. (Jena) Halle. 1902.

31. Vavilov, N. I.
On the origin of cultivated rye. Bull. Applied Botany (Russian) 10:561-590. (Resumé in English.) 1917.

32. ———
Studies on the origin of cultivated plants. Institut de Botanique appliquée et D'amélioration des Plantes. Leningrad. 1926.

33. Wright, Sewall
The effects of inbreeding and crossbreeding on guinea pigs. U. S. Dept. of Agr. Bul. 1121. 1922.

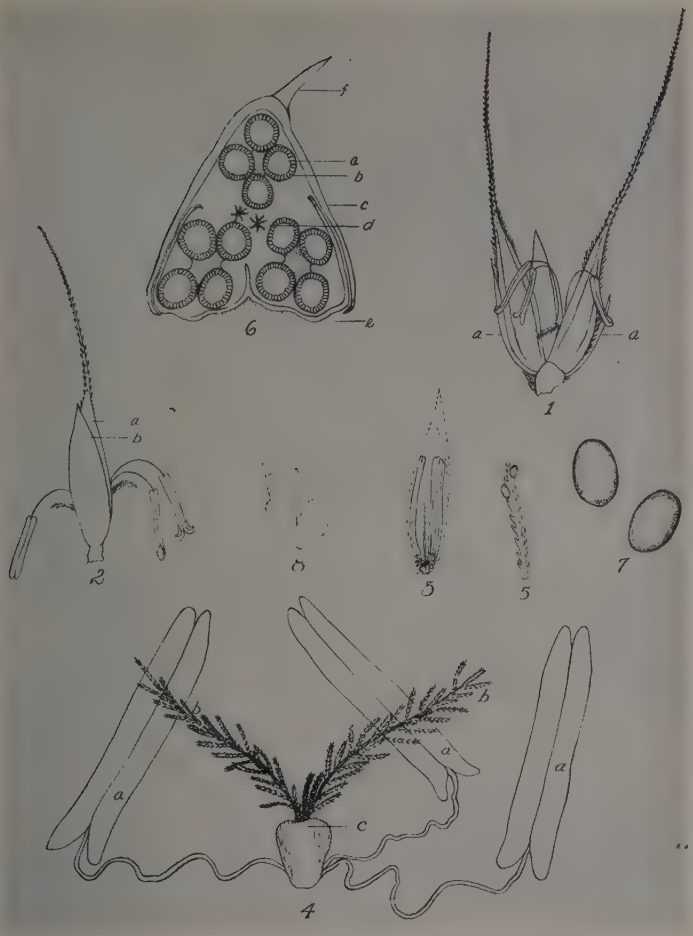


PLATE I

Details of Rye Inflorescence

1. Spikelet (x 2.0) consisting of two florets, right hand floret is flowering. a= glumes.
2. Single floret (x 2.3). a= lemma; b= palea.
3. Diagram of floret just before flowering (x 2.3).
4. Reproductive organs (x 9). a= anthers; b= two-parted feathery stigma; c= ovary.
5. Stigmatic branch with two attached pollen grains (x 30).
6. Cross-section of floret when the anthers are still green (x 18). a= anther sac; b= immature pollen grains; c= lemma; d= feathery stigma; e= palea; f= barb.
7. Mature pollen grains (x 450).
8. Two lodicules which attach to the base of the ovary and lie between it and the lemma (x 9).

TABLE XIII

AVERAGE PERCENTAGE SEED-SETTING OBTAINED IN SELFED STRAINS OF RYE, 1921 TO 1925

1921			1922				1923				1924				1925				Years selfed
Cult. No.	No. of plants	Percentage seed-setting of strain	Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		
					Parent plant	Strain			Parent plant	Strain			Parent plant	Strain			Parent plant	Strain	
											Minn. No. 92				R 2	7		1.5	1
											do				3	7		1.4	do
											do				4	1		0.4	do
											do				5	3		1.4	do
											do				6	2		0.8	do
											do				7	2		2.4	do
											do				9	2		3.7	do
											do				10	1		0	do
											do				11	1		0.3	do
											do				12	2		1.2	do
											do				13	4		5.5	do
											do				14	4		8.4	do
											do				15	1		1.1	do
											do				16	5		5.8	do
											do				17	5		1.0	do
											do				18	4		5.4	do
											do				19	4		1.9	do
											do				20	3		6.4	do
											do				21	3		7.7	do
											do				22	4		4.1	do
											do				23	3		0.8	do
											do				24	2		2.6	do
											do				25	4		1.6	do
											do				26	3		0.1	do
											do				27	4		4.0	do
											do				28	4		3.2	do
											do				29	4		2.6	do
											do				30	3		1.5	do
											do				31	3		4.4	do

TABLE XIII—*Continued*

AVERAGE PERCENTAGE SEED-SETTING OBTAINED IN SELFED STRAINS OF RYE, 1921 TO 1925

1921			1922				1923				1924				1925				Years selfed	
Cult. No.	No. of plants	Percentage seed-setting of strain	Cult. No.	No. of plants	Percentage seed-setting: Parent plant	Percentage seed-setting: Strain	Cult. No.	No. of plants	Percentage seed-setting: Parent plant	Percentage seed-setting: Strain	Cult. No.	No. of plants	Percentage seed-setting: Parent plant	Percentage seed-setting: Strain	Cult. No.	No. of plants	Percentage seed-setting: Parent plant	Percentage seed-setting: Strain		
							Minn.	No. 2			R 1	11		14.0	R32	1	11.3	4.8	1	
								do			38	20		15.3	33	3	73.3	2.2	do	
								do			38				34	3	5.6	2.3	do	
								do			87	13		11.0	35	5	6.9	2.2	do	
			Minn.	No. 2			R20	12		6.1	2	16	45.3	3.1	36	4	17.9	0.6	2	
				do			39	16		7.6	3	17	53.1	12.6	37	4	37.5	3.2	do	
				do			58	11		15.6	4	23	61.3	12.7	38	5	13.2	2.3	do	
											4				39	4	16.1	0.2	do	
				do			58				5	22	60.7*	4.5	40	5	14.8	5.4	+1	
											6	4	61.7	32.1	41	2	34.0	23.6	2	
				do			58				7	3	1.3	5.7	42	4	5.4	1.1	do	
				do			64	6		0.7	8	4	1.8	2.0	43	1	1.7	1.4	do	
R 5	41	2.6	R 5	6	38.6*	2.3	8	6	9.4	0.2	9	2	0.8	9.2	44	2	18.3	0	3	
5				6	56.8*	6.4	9	10	17.6	0.8	10	7	4.6*	2.3	45	3	5.2	7.8	1+1, 3	
				6			10	6	13.6	1.1	11	4	2.6	5.7	46	3	6.9	8.2	3	
6	9	21.2		11	19	42.5*	13.2	21	9	48.3	2.5	12	8	23.5*	2.3	47	4	1.7	2.0	1+1
				11				22	7	26.2	1.3	13	3	2.3	0.3	48	3	0.8	1.9	3
								23	15	19.5	1.5	14	8	57.3*	12.6	49	3	5.5	0.3	1+1
												14				50	3	81.3	1.2	do
				11				25	16	31.5	2.6	15	15	18.3	7.6	51	4	22.7	2.0	3
8	19	0.2		13	9	42.6*	4.3	27	7	17.5	1.2	16	12	40.9*	2.6	52	4	6.3	4.5	1+1
9	19	0.6		15	7	17.2*	3.0	30	7	3.5	10.2	17	17	50.0	24.6	53	3	52.9	5.2	3
												17				54	1	9.1	7.3	do
6	9	21.2		11	19	42.5*	13.2	24	7	62.5	2.2	18	10	13.8	5.0	55	6	19.8	1.2	do
												18				56	3	5.5	24.2	do
14	23	2.1		21	15	78.4*	20.9	36	12	33.1	2.2	19	3	0.8	2.2	57	2	2.4	4.6	do
												19				58	3	1.8	1.1	do
				21				37	9	44.0	1.0	21	12	51.7*	9.2	59	4	9.2	20.3	1+1

* = Sib crosses, i.e., heads of two sibs bagged together. † = Open pollinated.

\+ in years selfed column = Sib cross, thus 2+2 = 2 years selfed followed by a sib cross one year and two successive years selfed.

TABLE XIII *Continued*

AVERAGE PERCENTAGE SEED-SETTING OBTAINED IN SELFED STRAINS OF RYE, 1921 TO 1925

1921			1922				1923				1924				1925				Years selfed
Cult. No.	No. of plants	Percentage seed-setting of strain	Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		
					Parent plant	Strain			Parent plant	Strain			Parent plant	Strain			Parent plant	Strain	
R15	52	1.7	R25	21	73.5†	7.9	R41	6	41.0	4.7	R23	4	2.1	29.7	R60	1	1.5	0.3	3
15											23				61	4	76.1	51.5	do
19	11	0.7	26	11	37.1*	8.3	42	9	21.6	0.8	24	5	1.9	3.0	62	3	10.0	0.9	do
5	41	2.6	33	13	71.7†	6.2	46	12	21.1	1.2	28	8	4.5	12.6	63	5	81.7	19.2	do
			1	2	2.4	51.4	2	14	67.6	1.5	29	12	13.8	5.1	65	5	14.1	6.2	4
							2				30	4	1.3	12.2	66	1	10.1	0	do
5			2	8	9.6	3.5	4	11	12.5	5.0	31	11	7.5	19.5	67	5	76.8	31.4	do
											31				68	4	3.0	3.8	do
5			1	2	2.4	51.4	3	5	35.1	11.1	32	5	51.1	35.3	69	2	50.9	30.6	do
5			2	8	9.6	3.5	4	11	12.5	5.0	33	15	29.5	7.5	70	1	5.0	2.8	do
5			3	7	19.7	2.9	5	12	9.4	1.1	34	8	3.2	3.1	71	2	4.1	2.9	4, 2+1
											M.No.2				72	4		13.1	1
5			3	7	19.7	2.9	6	8	10.9	2.9	35	11	19.5	4.0	73	4	2.7	3.8	4
5			4	11	44.1	3.7	7	6	4.5	0.1	36	10	29.0*	8.9	74	2	2.6	40.0	2+1
14	23	2.1	20	7	3.3	18.3	33	8	9.6	4.8	37	11	14.8	8.8	75	5	10.5	25.9	4
			20				34	10	61.1	0.8	39	5	4.7	15.5	76	4	73.2	18.5	do
			20				35	11	21.3	3.9	40	4	4.1	3.5	77	4	10.2	0.6	do
15	52	1.7	23	4	12.8	6.0	38	10	18.1	2.7	43	13	16.4	9.2	78	4	43.4	1.3	do
											43				79	5	6.2	34.1	do
15			24	8	4.1	1.4	40	4	2.2	1.1	44	5	1.4	2.3	80	3	1.3	25.7	do
23	47	1.7	38	10	35.9	11.7	51	10	34.1	0.2	46	8	10.9*	4.7	81	2	13.9	2.2	2+1
			38				52	10	26.0	0.9	47	2	20.5*	3.3	82	4	5.6	1.2	do
24	61	2.8	40	9	3.2	7.4	53	8	21.6	3.2	48	5	4.9	8.8	83	7	15.3	11.4	4
			40				54	9	14.7	3.3	49	3	4.8	49.3	84	1	38.5	16.5	do
24			41	8	15.3	16.6	56	9	41.0	5.6	52	15	39.9*	9.5	85	5	18.7	1.3	2+1
											52				86	4	3.6	4.3	do

* = Sib crosses, i.e., heads of two sibs bagged together. † = Open pollinated.

\+ in years selfed column = Sib cross, thus 2+2 = 2 years selfed followed by a sib cross one year and two successive years selfed.

TABLE XIII—*Concluded*

AVERAGE PERCENTAGE SEED-SETTING OBTAINED IN SELFED STRAINS OF RYE, 1921 TO 1925

1921			1922				1923				1924				1925				Years selfed
Cult. No.	No. of plants	Percentage seed-setting of strain	Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		Cult. No.	No. of plants	Percentage seed-setting		
					Parent plant	Strain			Parent plant	Strain			Parent plant	Strain			Parent plant	Strain	
R24			R42	8	27.8	17.7	R59	7	30.4	8.6	R53	14	20.2	16.5	R87	4	81.8	28.4	4
											53				88	1	7.3	14.3	do
			42				60	6	54.8	8.7	54	11	26.5	20.4	89	2	47.5	8.5	do
							60				55	14	7.2	11.2	90	4	27.4	3.2	do
6	9	21.2	7	5	4.0	3.1	11	16	9.5	1.2	56	9	4.7	6.4	91	4	8.3	0.3	5
6			8	10	15.0	4.1	13	8	6.6	4.9	58	10	14.3	7.2	92	4	19.2	6.3	do
			8				14	12	64.7*	2.5	60	6	12.2	10.2	93	5	34.0	9.2	2+2
6			9	14	51.7	3.0	16	10	3.6	0.3	61	8	27.7*	5.8	94	4	27.7	6.3	3+1
6			10	12	60.9	13.5	18	8	2.7	2.3	62	4	4.3	27.3	95	4	80.3	14.5	5
											62				96	3	1.7	6.5	do
			10				19	11	54.3	0.9	63	4	1.3	16.8	97	6	66.4	9.9	do
9	19	0.6	14	4	2.4	19.9	28	11	9.3	3.2	64	7	6.2	19.7	98	2	1.9	3.0	do
8	19	0.2	12	1	1.9	80.3	26	7	80.3	16.8	65	1	69.6	55.0	99	6	55.0	10.0	do
10	6	0.6	16	1	1.5	35.4	31	6	35.4	3.9	67	5	1.9	11.1	100	3	35.4	22.7	do
11	16	0.6	18	2	2.8	6.3	32	14	12.5	3.1	69	7	6.6	6.0	101	5	14.0	0.9	do
18	7	0.5	29	1	1.3	12.5	43	4	12.5	14.6	70	8	56.4	53.2	102	6	91.1	3.2	do
21	10	2.3	34	6	4.7	22.8	48	14	25.5	6.2	72	10	6.6	17.7	103	9	31.4	11.2	do
			34				49	4	51.1	0.8	74	18	45.5*	39.3	104	6	71.7	26.9	3+1
											74				105	1	1.8	0	do
18	7	0.5	30	1	7.8	1.2	65	1	1.2	1.3	75	3	1.3	13.4	106	3	17.5	3.5	5
							102-1				83	7	5.7	24.8	107	5	3.8	5.1	2
							15 yld. test				84	6		6.0	108	4	17.6	10.0	1
							42 yld. test				85	7		11.4	109	6	9.1	4.9	do
											1501				110	1		4.2	do

* = Sib crosses, i.e., heads of two sibs bagged together. † = Open pollinated.

\+ in years selfed column = Sib cross, thus 2+2 = 2 years selfed followed by a sib cross one year and two successive years selfed.

TABLE XIV

YIELD AND HEIGHT OF SELFED STRAINS IN COMPARISON WITH COMMERCIAL MINNESOTA NO. 2 RYE USED AS A CHECK

1925 Cult. No.	No. years selfed	Yield						Height					
		1923		1924		1925		1923		1924		1925	
		Grams	Per cent	Grams	Per cent	Grams	Per cent	Inches	Per cent	Inches	Per cent	Inches	Per cent
C-3	1					132.2	96					48	108
5	do.					183.8	134					52	117
7	do					121.4	88					50	112
6	do					135.2	98					52	117
4	2			141.0	60	109.7	80			60	102	48	108
9	do			239.3	102	123.2	90			66	112	50	112
10	do			239.3	102	158.1	115			66	112	50	112
11	+1			194.2s	83	97.8	71			58s	98	42	94
12	2			85.3	36	11.9	9			54	92	36	81
13	do					101.5	74					44	99
15	3	60	48			9.4	7	50	104			40	90
11 (1924)	1+	123	99	101.1s	43			49	102	60s	102		
16	3	123	99	187.8s	80	176.0	128	49	102	56s	95	45	101
13 (1924)	1+	91	73	143.3s	61			42	88	58s	98		
15 (1924)	do	109	88	140.8s	60			46	96	58s	98		
17	1+1	109	88	140.8s	60	25.8	19	46	96	58s	98	42	94
18	3	75	60	154.9	66	172.8	126	46	96	58	98	44	99
19	1+1	64	52	87.8s	37	108.5	79	46	96	52s	88	42	94
21	3	67	54	26.2	11	5.6	4	47	98	54	92	36	81
22	3	82	66	291.8	124	122.6	89	49	102	62	105	36	81
22 (1924)	1+	98	79	323.2s	138			52	109	58s	98		
23	1+1	72	58	121.0s	52	179.3	130	49	102	58s	98	40	90
24 (1924)	1+	94	76	210.3s	90			46	96	50s	85		
24	3	94	76	210.3s	90	37.5	27	46	96	50s	85	32	72
25 (1924)	2	38	31	10.7	5			42	88	46	78		
25	3	149	120	173.4s	74	31.4	23	48	100	56s	95	38	85
27	4	119	96	245.3	104	176.9	129	53	111	56	95	44	99
28	do	119	96	245.3	104	92.8	68	53	111	56	95	40	90

s = sib-pollination.

TABLE XIV—*Continued*

YIELD AND HEIGHT OF SELFED STRAINS IN COMPARISON WITH COMMERCIAL MINNESOTA NO. 2 RYE USED AS A CHECK

1925 Cult. No.	No. years selfed	Yield						Height					
		1923		1924		1925		1923		1924		1925	
		Grams	Per cent	Grams	Per cent	Grams	Per cent	Inches	Per cent	Inches	Per cent	Inches	Per cent
C-29	4	28	23	256.2	109	30.2	22	45	94	58	98	38	85
30	do	145	117	60.5	26	27.2	20	40	84	44	75	32	72
30 (1924)	3	28	23	256.2	109			45	94	58	98		
31 (1924)	do	124	100	157.4	67			50	104	54	92		
31	2+1	81	65	145.7s	62	141.3	103	45	94	52s	88	42	94
33	4	75s	60	243.7	104	44.6	32	46s	96	52	88	38	85
34	do	117	94	132.3s	56	244.0	178	52	109	56s	95	44	99
36 (1924)	3	20	16	198.9	85			48	100	58	98		
35	4	95	77			140.3	102	44	92			44	99
36	2+1	42	34	201.8s	86		123	46	96	56s	95	36	81
37	4	80	65	103.1	44	52.5	38	49	102	54	92	42	94
39	do	53	43	200.7	85			46	96	58	98	32	72
41 (1924)	3	76	61	108.7	46			48	100	54	92		
40	2+1	86	69	154.7s	66	30.1	22	57	119	54s	92	40	90
41	4	69	56	81.3	35	45.2	33	46	96	54	92	32	72
42	do	69	56	81.3	35	30.1	22	46	96	54	92	30	67
43	do	72	58	99.6	42	189.4	138	47	98	46	78	32	72
45	do	72	58	125.7	54	116.7	85	47	98	48	81	34	76
46	5	170	137	198.0s	84	211.5	154	52	109	56s	95	44	99
49	do	87	70	55.3	24	63.2	46	47	98	54	92	44	99
51	2+2	160s	129	229.0	98	116.4	85	49s	102	56	95	42	94
52	3+1	22	18	148.2s	63	112.8	82	46	96	56s	95	42	94
53	5	94	76	156.0	66			46	96	56	95	39	88
54	do	20	16	236.4s	101	202.5	147	41	86	56s	95	40	90
55	do	110	89	249.2s	106	152.6	111	49	102	60s	102	44	99
57	do	53	43	75.8	32			41	86	48	81	36	81
58	do	34	27	105.0	45	55.3	40	49	102	58	98	30	67
59	do			128.2	55	149.1	109			58	98	40	90
60	do	14	11	63.8	27	58.1	42			56	95	36	81
61	do	127	102	107.2	46	212.8	155	51	106	54	92	48	108
63	3+1	44	35	184.3s	78	143.5	104	46	96	58s	98	40	90
66	1			181.2	77	155.0	113			60	102	44	99

s = sib-pollination. + in years selfed column = Sib cross, thus 2+2 = 2 years selfed followed by a sib cross one year and two successive years selfed.

TABLE XIV—*Concluded*

YIELD AND HEIGHT OF SELFED STRAINS IN COMPARISON WITH COMMERCIAL MINNESOTA NO. 2 RYE USED AS A CHECK

1925 Cult. No.	No. years selfed	Yield						Height					
		1923		1924		1925		1923		1924		1925	
		Grams	Per cent	Grams	Per cent	Grams	Per cent	Inches	Per cent	Inches	Per cent	Inches	Per cent
C4 (1924)	1			200.7	85					60	102		
63 do	4			97.1	41					58	98		
70 do	do			59.0	25					44	75		
71 do	do			40.5	17					38	64		
72 do	do			36.7	16					56	95		
6 (1923)	2	114	92					50	104				
16 do	3	87	70					43	90				
44 do	do	14	11										
47 do	do	34	27					49	102				
48 do	2	34	27					46	96				
63 do	3	14	11										
65 do	3	22	18					45	94				
76 do	2	83	67					50	104				
88 do	do	8	6										
Minn. No. 2		73	59	209.1	89	131.4	96	46	96	60	102	52	117
do		140	113	306.7	131	86.7	63	43	90	64	108	48	108
do		147	119	239.3	102	133.2	97	48	100	60	102	44	99
do		113	91	306.8	131	197.7	144	48	100	58	98	44	99
do		134	108	266.6	114	135.3	98	46	96	56	95	44	99
do		138	111	253.7	108	68.2	50	44	92	58	98	44	99
do		132	106	249.8	106	61.6	45	49	102	56	95	44	99
do		103	83	252.2	107	146.1	106	49	102	56	95	40	90
do		77	62	282.1	120	217.3	158	50	104	58	98	44	99
do		98	79	208.8	89	143.3	104	48	100	58	98	44	99
do		118	95	162.3	69	190.3	139	51	106	62	105	44	99
do		112	90	182.2	78	137.5	100	48	100	60	102	42	94
do		160	129	209.8	89			52	109	60	102		
do		159	128	158.3	67			50	104	60	102		
do		130	105					48	100				
do		149	120					46	96				
Mean of checks		124	100	234.8	100	137.4	100	47.9	100	59	100	44.5	100

s = sib-pollination. + in years selfed column = Sib cross, thus 2+2 = 2 years followed by a sib cross one year and two successive years selfed.

TECHNICAL BULLETIN 41 SEPTEMBER 1926

University of Minnesota
Agricultural Experiment Station

Low Temperature and Moisture as Factors in the Ecology of the Rice Weevil, Sitophilus oryza L. and the Granary Weevil, Sitophilus granarius L.

By William Robinson
Division of Entomology and Economic Zoology

UNIVERSITY FARM, ST. PAUL

CONTENTS

Page

Introduction 3

Temperature

Grain weevils and their normal relations to low temperatures 4
Previous work on resistance of grain weevils to low temperatures 4
Stock culture of weevils 4
Method of obtaining weevils from the stock culture 5
Technic of handling the weevils throughout the tests 5

Moisture

Grain weevils and their moisture problem 16
Previous work on the relation of grain weevils to moisture 17
Effect of moisture content of wheat upon moisture content of grain weevils 17
Effect of moisture content of wheat upon weight of weevils 19
Fluctuations in moisture content of wheat and responsive changes in weight and moisture content of grain weevils 21
Effect of moisture content of wheat on the freezing point of grain weevils 23
Optimum, maximum and minimum moisture content of wheat required by grain weevils 24
Attractiveness of wheat having various percentages of moisture 26
Dry wheat and mortality of weevils 28
Effect of exposure to low temperature upon moisture content of grain weevils 30
Effect of moisture content of wheat on resistance of grain weevils to low temperatures 32
Comparative moisture-retaining capacity of grain weevils 35
Effect of weevil infestation upon moisture content of wheat 36

Temperatures of grain stored in terminal elevators, with the suggestion of a possible means of controlling grain weevils 38

Summary 40

Literature cited 41

ILLUSTRATIONS

Fig. 1. Form used in recording details of exposures 6
Fig. 2. Percentage of mortality obtained with *S. oryza* at 7.2°, 1.6°, and —1.1° C. 8
Fig. 3. Percentage of mortality obtained with *S. oryza* at —6.6°, —12.2°, and —17.7° C. 8
Fig. 4. Percentage of mortality obtained with *S. granarius* at 1.6°, —1.1° and —6.6° C. 9
Fig. 5. Percentage of mortality obtained with *S. granarius* at —12.2° and —17.7° C. 9
Fig. 6. Loss of weight during dormancy 12
Fig. 7. Loss of weight during activity at room temperature, 22° C., no food being supplied 13
Fig. 8. Comparison of results obtained with *S. oryza* under conditions of sudden and gradual exposures 14
Fig. 9. Results of interrupted and continuous exposures on *S. oryza* 16
Fig. 10. Electrode and holder used in moisture determinations 18
Fig. 11. Fluctuations in weight and moisture content of *S. oryza* following changes in moisture content of wheat 22
Fig. 12. Fluctuations in weight and moisture content of *S. granarius* following changes in moisture content of wheat 22
Fig. 13. Correlation of moisture content of wheat and freezing point of weevils 23
Fig. 14. Under side of tube showing graded accumulation of whitish feces 27
Fig. 15. Comparative effect of whole and broken dried wheat on mortality of *S. oryza* 28
Fig. 16. Comparative effect of whole and broken dried wheat on mortality of *S. granarius* 29
Fig. 17. Disturbing effect of moderately low temperatures upon moisture content of dormant weevils 31
Fig. 18. Rise in moisture content of active weevils during starvation and decline with approaching death 32
Fig. 19. Comparative resistance of *S. granarius* to —12.2° C. when fed on normal and moist wheat 33
Fig. 20. Comparative resistance of *S. oryza* to —1.1° C. when fed on wheat of various moisture contents 34
Fig. 21. Correlation of moisture content of wheat and length of exposure required to kill grain weevils 34
Fig. 22. Comparative rate of drying out of tissues after death 35
Fig. 23. Temperature of a 60-foot tank of wheat during a period of seven months 39

LOW TEMPERATURE AND MOISTURE AS FACTORS IN THE ECOLOGY OF THE RICE WEEVIL, *SITOPHILUS ORYZA* L., AND THE GRANARY WEEVIL, *SITOPHILUS GRANARIUS* L.

By William Robinson

INTRODUCTION

The factors of temperature and moisture occupy a vitally important place in the environment of any organism. In their effects on the individual these factors are so closely inter-related that a complete study of one can not be made without regard to the other. This treatise presents a study of the comparative susceptibility of two species of grain weevils to low temperatures and to varying amounts of moisture. Each factor is treated separately by holding one constant and varying the other.

The investigation has been facilitated by the excellent equipment of the Division of Entomology and Economic Zoology for studying the effects of temperature and moisture.

The type of insects used in this research has greatly lightened the routine work. Grain weevils appear to possess some advantages in the study of certain phases of biological phenomena, not the least being the ease with which they may be obtained at all times of the year. They require very little attention, and with a slight amount of care may be bred in the laboratory by thousands. They are also easily handled. Their food requirements are simple, and when once satisfied—with a "measure of wheat"—they will maintain and reproduce themselves throughout the year in countless numbers. With experiments, as in the series reported on, in which quantity determinations add special value to the data, grain weevils (within the limits of their adaptability) have much to recommend them.

Acknowledgments are due to Dr. R. N. Chapman, chief of the division, at whose suggestion the study of the comparative resistance of the grain weevils to low temperatures was begun and who conceived the idea of controlling by low temperatures weevils infesting stored grain; to Dr. C. H. Bailey, of the Division of Agricultural Biochemistry, and to Dr. Anthony Zeleny, of the Department of Physics, for their kind assistance in certain phases of the problem.

TEMPERATURE

GRAIN WEEVILS AND THEIR NORMAL RELATIONS TO LOW TEMPERATURES

Throughout their entire life cycle, grain weevils and rice weevils live normally in stored grain. In this environment they are not exposed to extremes of low temperature, for grain in storage is a poor conductor of heat. It absorbs and gives off heat very slowly and can remain all winter above the freezing point of water. Thus the matter of encountering and surviving the cold of winter—a problem of the first importance to many insects—is one to which they have no need to adapt themselves. Having developed no resistance to cold, they afford an opportunity of studying the effects of low temperatures upon an organism which can do nothing to offset its injuries.

PREVIOUS WORK ON RESISTANCE OF GRAIN WEEVILS TO LOW TEMPERATURES

Dendy and Elkington (1920) exposed both species to temperatures of 33°-36° F. for 11 days and found that 9 per cent of *granarius* and 97 per cent of *oryza* were killed.

Back and Cotton (1924) conducted an extended series of experiments upon the two species, exposing them to a graded series of temperatures ranging from 0° F. to 60° F. They found *granarius* in every instance to be the more resistant. From their data may be seen also an interesting correlation between the degree of temperature and the time required to kill. That is, by raising the temperature the length of exposure was greatly increased and a line representing this correlation would take the form of a hyperbola.

STOCK CULTURE OF WEEVILS

In the present series of experiments it was endeavored to rear the insects under as nearly uniform conditions of temperature and moisture as was possible in the laboratory. Metal tanks 30 inches high and 30 inches in diameter, each containing several bushels of wheat, were used. In summer the temperature of the laboratory ranged from 70° to 80° F. and in winter between 65° and 75° F. In summer, the moisture content of the wheat in the tanks remained from 13 to 14 per cent; but in winter, with a relative humidity as low as from 25 to 10 per cent, wheat exposed in the laboratory dried down to 10 per cent moisture. However, a pan of water in each tank prevented the moisture content of the wheat from going below 13 per cent. Weevils were not allowed to accumulate in the tanks in large numbers, as that tended to change both the moisture content and the temperature of the wheat.

METHOD OF OBTAINING WEEVILS FROM THE STOCK CULTURE

The means of obtaining the insects in large numbers from the mass of wheat in which they live was very simple and effective. When grain weevils are disturbed they come to the surface of the grain and climb the sides of the container, so the grain was stirred thoroly and when a large number of individuals had collected on the sides they were swept with a brush on to a piece of cardboard shaped to fit the inside of the tank. The granary weevil has more difficulty than the rice weevil in climbing a smooth surface, so the inside of the granary weevil tank was lined with rough paper.

TECHNIC OF HANDLING WEEVILS THROUGHOUT TESTS

After the weevils had been collected they were transferred to glass vials which had been cooled to the temperature of the exposure, and then placed in the refrigerating cabinet. The most satisfactory containers were 3 inches high and 1⅛ inches in diameter. Each was fitted with a cork stopper having a ⅜-inch hole covered with wire screening. They were easily and quickly handled and occupied little space.

A record of each experiment was made on a form similar to that shown in Figure 1. As each container was removed from the refrigerator, the weevils were placed in a petrie dish 5 inches in diameter and ½ inch high and were counted while still dormant. By the use of petrie dishes the activities of the insects could be observed without disturbing them. This was necessary in taking counts because of their habit of feigning death when disturbed. The effect of exposure was classified as follows: (1) motionless, (2) feebly kicking, (3) feebly crawling, (4) actively climbing. These divisions were arbitrary and not always well marked, as there were frequent gradations from one to the other, but in general they were satisfactory. They also provided a means of recording quickly the effect of insufficient exposure, for, as mentioned later, it was planned to run a graded series of exposures at each given temperature in order to study the effect of a partial exposure.

Observations on the condition of the weevils in the petrie dishes were made until they became motionless or regained activity; and no experiment was closed until columns 2 and 3 in the chart could be marked with a zero. This sometimes required from two to five days. A few grains of wheat were added to maintain the active weevils. When each experiment was closed the insects were destroyed, and none were used for more than one experiment, as it was thought possible that the previous treatment might affect their resistance to subsequent exposures.

Checks.—Check experiments were conducted for every series exposures. As soon as a series was placed in the refrigerator, at lea 3 checks, each containing about 150 individuals, were prepared fro the same stock culture and kept under normal conditions of temper ture and moisture. When the series of exposures was terminated, t dead in the checks were counted and all were destroyed. No indivi uals in the checks were used a second time. In all, 47 check expe ments, or 7582 individuals, were used. The mortality was always ve low, even in exposures of 30 or more days, and never exceeded per cent.

EFFECT OF LOW TEMPERATURES ON GRAIN WEEVILS
Series A-1

Experiment No... 394 Container No..19.... Species: granarius oryza

Exposure Started: Day.... Oct. 29 Hour.....5:30 p.m.....

Exposure Finished: Day....Oct. 31..... Hour.....1:30 p.m.....

Length of Exposure: Days.....1..... Hours.....20.....

Temperature to be dropped to 20...°F Cabinet.....C.....

Any Variation in Temperature?....No..... Mean Temperature.....20...°F

Individuals in Experiment...231...No. Killed..162....% Killed..70.1.....

148-152-162

Individuals in Checks.....No..dead in Checks at end of Exp..2-2-1....

Activities after Exposure

TIME in hours after exposure	Motionless	Feebly Kicking	Feebly Crawling	Actively Climbing
24	221	10	-	-
72	136	others	6	-
96	92	"	8	3
120	81	"	3	17
160	others	-	-	69

Remarks:

Fig. 1. Form Used in Recording Details of Exposures

Refrigerating outfit.—Low temperatures were obtained by a tw ton automatic refrigerating machine and a constant temperature a humidity cabinet with a recording wet and dry bulb thermometer. Th equipment gave the utmost satisfaction, and temperatures varying n more than one-half of a degree Centigrade were obtained regular even over extended periods.

Constant temperatures.—The uniformity of the temperatures, as mentioned above, which were obtained during the experiments, was of special value, as no data were available on the effect of constant temperatures upon these two species of insects. In the work of Back and Cotton (1924) temperatures approaching constancy were used, but even there a spread of at least 5° F. usually occurred. Later it will be shown that a difference of 5° F. in the temperature materially affects the percentage of mortality at any given length of exposure.

Number of weevils used.—It was discovered early in the work that, despite the fact that the weevils were obtained from a common culture, the resistance of individuals to low temperatures varied considerably. Large numbers, consequently, had to be used in order to present as accurate data as possible. The rapidity with which both species, especially *oryza,* increase always assured a plentiful supply for the experiments. In the series of experiments on low temperatures, 129,477 insects were used; and in those on moisture, over 60,000 were used.

Full and partial exposures.—The time necessary to obtain 100 per cent mortality was determined for some experiments, while for others it was desired to note the effect of shorter exposures upon the percentage of mortality. Thus, removals from the refrigerator were begun early and were continued at intervals until full exposure had been made.

Abrupt and gradual exposures.—In one series of experiments, weevils were transferred directly from the stock culture to the low temperature at which they were to be tested. In other series they were brought down gradually by decreasing slowly the temperatures between dormancy and the final exposure. The latter procedure was planned to determine if the process of "hardening" observed by Payne (1926) with oak borers would increase the resistance of these grain weevils to low temperatures.

Range of temperatures used in abrupt exposures.—Beginning with the temperature at which each species became dormant, the following range of temperature was used:

TABLE I

RANGE OF TEMPERATURE USED

S. oryza		*S. granarius*	
Degrees C.	Degrees F.	Degrees C.	Degrees F.
7.2	45	1.6	35
1.6	35	−1.1	30
−1.1	30	−6.6	20
−6.6	20	−12.2	10
−12.2	10	−17.7	0
−17.7	0		

For each of these temperatures about 25 experiments were run, each having between 150 and 250 individuals.

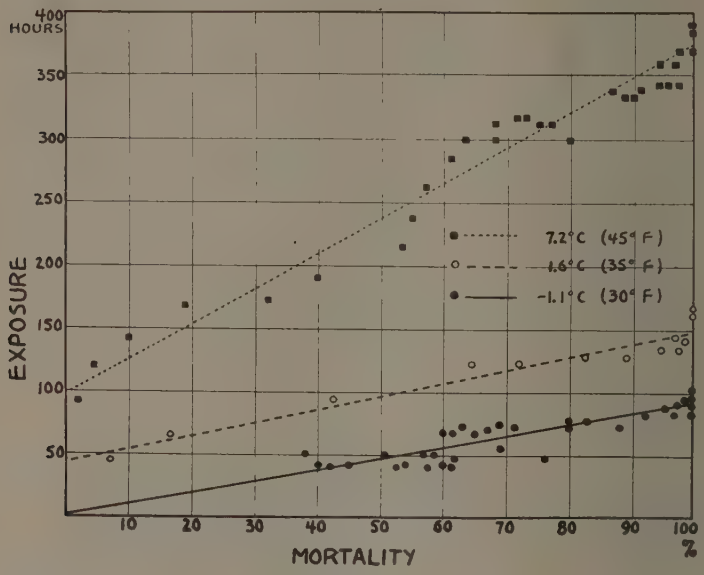


Fig. 2. Percentage of Mortality Obtained with *S. oryza* at 7.2°, 1.6°, and —1.1° C.

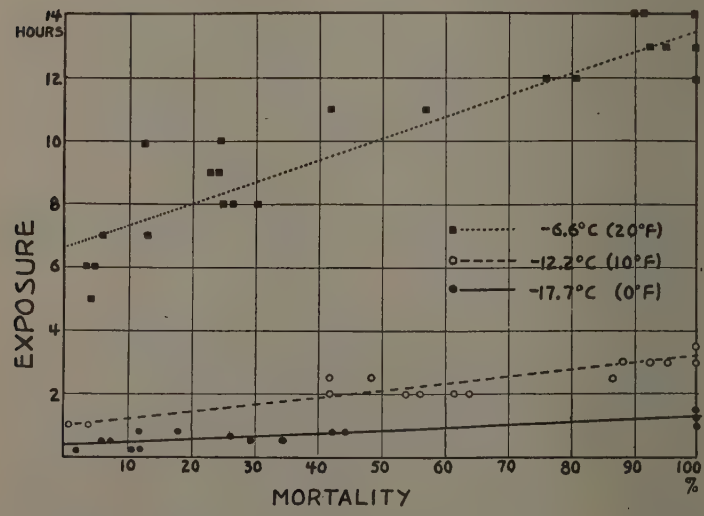


Fig. 3. Percentage of Mortality Obtained with *S. oryza* at —6.6°, —12.2°, and —17.7° C.

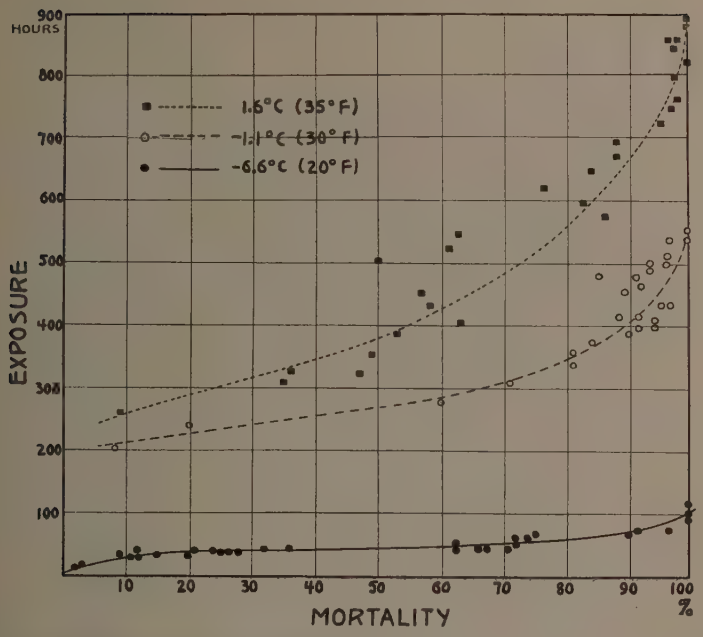


Fig. 4. Percentage of Mortality Obtained with *S. granarius* at 1.6°, —1.1°, and —6.6° C.

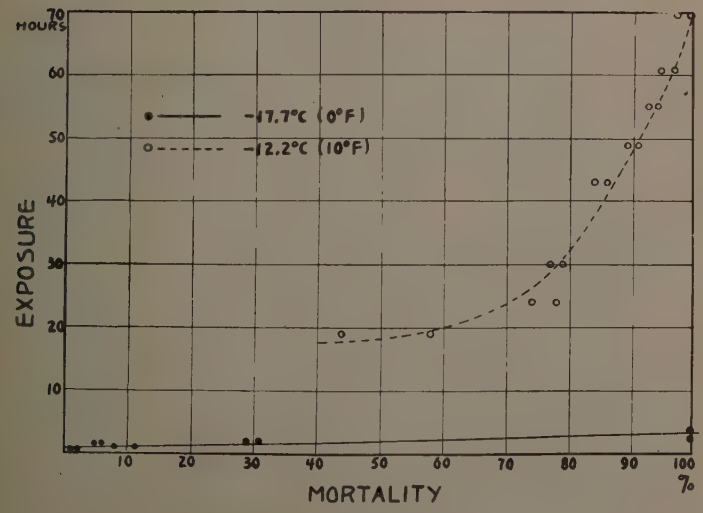


Fig. 5. Percentage of Mortality Obtained with *S. granarius* at —12.2° and —17.7° C.

Discussion of results of abrupt exposures.—The effects on *oryza* of the graded series of low temperatures are shown in Figures 2 and 3; and of those on *granarius*, in Figures 4 and 5. These charts show the duration of exposures in hours. The time required to obtain 100 per cent mortality is a great deal less than was found necessary by Back and Cotton (1924). A possible explanation of this difference is that the moisture content of their stock cultures might have been considerably higher than that used in these experiments. Here the weevils were reared in cultures of wheat having approximately 13 to 14 per cent moisture content. It is shown later, in the discussion of moisture as a factor, that the moisture content of the wheat has a marked effect upon the resistance of these insects to low temperatures.

A well marked correlation between length of exposure and percentage of mortality for any given temperature, is observable in all the charts. The curve representing this correlation is practically a straight line for *oryza* and a curved one for *granarius*. It is evident that an increase or a decrease in the length of exposure, within the limits of the experiment, would bring about a corresponding change in the percentage of mortality.

Exposures required to obtain full mortality at the different temperatures used are given in Tables II and III. These also show that the lower the temperature the shorter is the necessary exposure. A correlation curve for time and temperature would probably take the form of a hyperbola, as observed for Back and Cotton (1924).

TABLE II

TIME REQUIRED AT VARIOUS TEMPERATURES TO KILL *S. oryza*

Fig. No.	Temperature		Av. length of exposure, hrs.	No. of experiments conducted	No. of individuals used
2	7.2° C.*	(45° F.)	350	39	10,534
2	1.6	35	160	15	2,306
2	—1.1	30	98	72	16,278
3	—6.6	20	14	58	15,374
3	—12.2	10	3½	24	3,243
3	—17.7	0	1½	32	3,519

* Temperature at which dormancy occurs.

TABLE III

TIME REQUIRED AT VARIOUS TEMPERATURES TO KILL *S. granarius*

Fig. No.	Temperature		Av. length of exposure, hrs.	No. of experiments conducted	No. of individuals used
4	1.6° C.*	(35° F.)	875	32	7250
4	—1.1	30	545	36	5359
4	—6.6	20	100	42	7170
5	—12.2	10	70	22	3026
5	—17.7	0	2½	28	4291

* Temperature at which dormancy occurs.

The greater susceptibility of *oryza* to low temperatures, noted by previous workers, is confirmed. This difference in resistance of the two species to cold probably accounts in part for the fact, as mentioned by Cotton (1921), that *oryza* is found more abundantly in the South;[1] while *granarius,* altho a pest of stored grain in warm climates, can also be found well distributed northward.

Inability to endure dormancy.—These insects came originally from the tropics, it is believed, where, not having to endure the cold of winter as in the temperate and frigid zones, they apparently never developed the ability to hibernate; or, having once possessed this characteristic, have lost it through disuse. Living normally in stored grain, the temperature of which fluctuates very little and seldom goes below the freezing point of water even during our northern winters, it has been possible for these two species to spread north and south and still to be protected largely from low temperatures.

If the temperatures at which these insects normally live be gradually diminished, a corresponding decrease in the rate of their activities will occur until at approximately 7.2° C. (45° F.) with *oryza* and 1.6° C. (35° F.) with *granarius,* the weevils collapse and become motionless. They make no effort to avoid the approach of low temperatures, neither are they stimulated into assuming any resistant condition; they merely move more and more sluggishly as the environment becomes colder and finally fall into a state of dormancy. Neither species can endure this condition. *Oryza* perishes in 400 hours, approximately 17 days; and *granarius* in 930 hours, approximately 38 days.

Effect of low temperatures upon weight.—During the course of exposure to various low temperatures, the weight of 500 weevils of each species was taken daily until deaths began to occur. From the first day a loss of weight was noticed, and this decrease was so nearly constant that the daily loss could be closely predicted. The correlation between percentage of weight and length of exposure is shown in Figure 6. This is a straight line correlation for both species at the temperatures at which they become dormant. With the approach of death a slight increase in loss occurred. At these temperatures *granarius* lost 18 per cent and *oryza* 24 per cent of their original weight. This coincides with the fact that *granarius* can endure dormancy for a longer period.

A comparison is also made of the loss of weight of *oryza* at two different temperatures. At 7.2° C. (45° F.) the loss is 24 per cent at time of death, while at 1.6° C. (35° F.) it is only 12 per cent. This indicates that other factors besides the depletion of the body tissues by metabolic processes are responsible for the inability of these insects to endure dormancy.

[1] In the observations on moisture, it is mentioned that the difference in susceptibility to low moisture content of wheat may affect in part the northerly distribution of the two species.

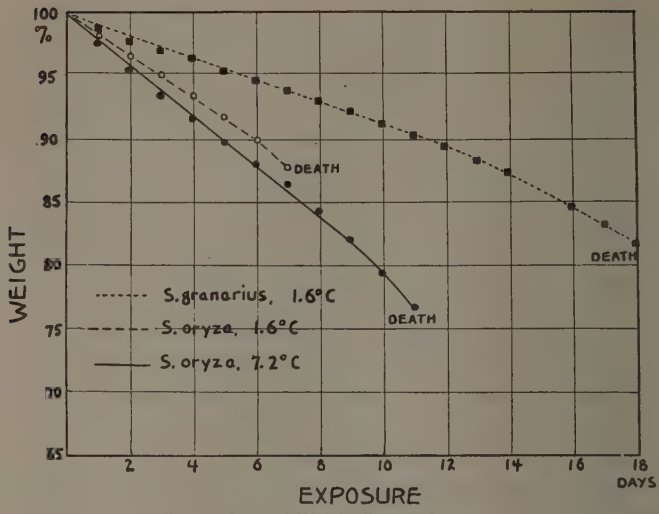


Fig. 6. Loss of Weight During Dormancy

Tests were made, for a check, on the loss of weight of each species when kept without food at room temperature, approximately 22.2° C. (72° F.). The weevils were all unusually active and seemed to be made very restless by the absence of food. Their activity continued until exhaustion set in. Death began to occur on the sixth day, at which time this experiment was terminated. As with the other tests, the straight line correlation is evident (Fig. 7). The loss of weight with *oryza* was 44 per cent and with *granarius* 33 per cent.

This marked and continuous loss of weight doubtless explains in part why these insects are unable to endure dormancy. Their inability can be attributed to a persistence in the rate of metabolism even while exposed to low temperatures. The reason for this is unknown. Rasmussen (1916) reviews a number of theories advanced by various workers to account for the phenomenon of hibernation during which period metabolism and the consequent breaking down of tissues are reduced to an extremely low rate. He states, however, that all the theories are based upon insufficient data, hence many of them are of little value. The same author (1923) reviews the extensive literature on the so-called hibernating gland of mammals which has been claimed by some writers to secrete a substance of significance to hibernating animals. Here, also, this author states that the evidence as to this gland having any bearing on hibernation is inconclusive. Thus, in the absence of precise data on the cause of dormancy in hibernating animals, it is especially difficult to determine what is lacking in animals which are killed by low temperatures because they can not hibernate.

Discussion of the gradual exposures.—To determine if grain weevils could withstand low temperatures for a longer period if exposed to them gradually, the following tests were made. From the stock culture, which had a temperature of 21° C. (70° F.), 11,162 rice weevils were placed in standard containers with wheat from their culture. They were then exposed in the refrigerator to 10° C. (50° F.) for 72 hours, during which time they moved very sluggishly in the wheat. Further reductions were made—to 7.2° C. (45° F.) for 65 hours, to 4.4° C. (40° F.) for 48 hours, and to 1.6° C. (35° F.) for 36 hours. The time in each case was calculated to be not more than one-sixth the fatal exposure, and it was expected that none would perish. This was preparatory to a final exposure of —1.1° C. (30° F.), at which temperature the test of resistance was to be made.

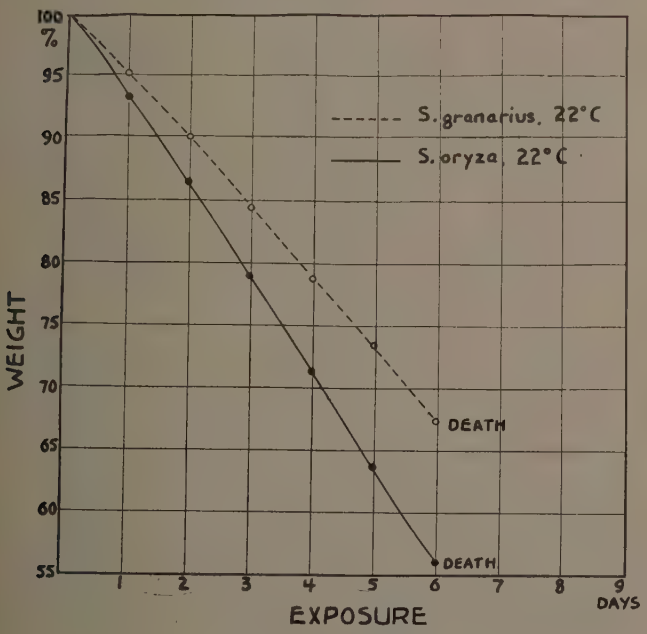


Fig. 7. Loss of Weight During Activity at Room Temperature, 22° C., No Food Being Supplied

Each time the temperature was reduced a container with about 200 individuals was removed permanently from the cabinet. In every case, none of the insects showed any signs of injury and all became active in a few minutes after removal. This is an important point, as it showed that all the insects were alive at the beginning of the final exposure.

When the temperature of —1.1° C. was begun, 32 containers with 8941 rice weevils were placed in the cabinet to serve as checks. These weevils had just been taken from the same culture as the others and had not been previously subjected to low temperatures. The exposure to —1.1° C., therefore, began simultaneously with both series, and from that time on both were treated alike. Containers were removed at short intervals and the results are shown in Figure 8.

It is evident from a study of this chart that instead of their resistance being increased by a gradual exposure to low temperature, these weevils were actually killed in a much shorter time than by an abrupt exposure. For instance, 65 per cent were killed in 36 hours under a gradual exposure, while to obtain an equal mortality with a sudden drop required 95 hours; and to obtain 37 per cent mortality required 24 hours with the former treatment and 72 hours with the latter.

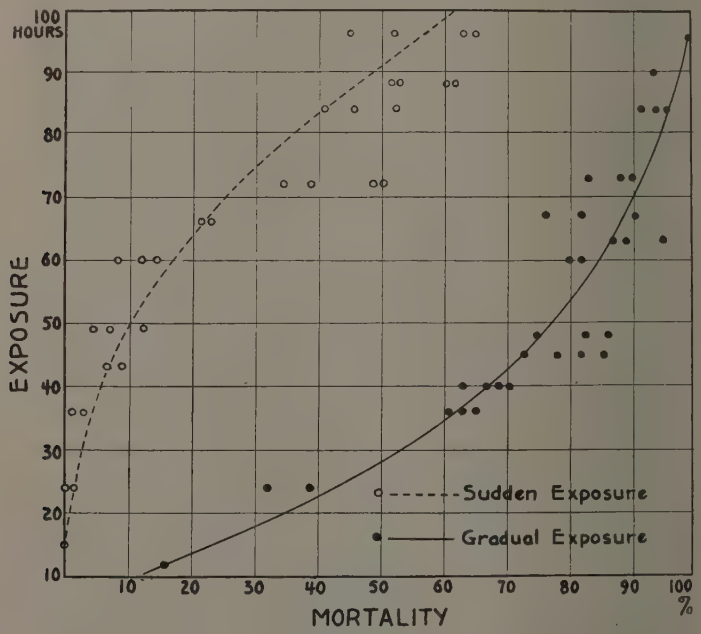


Fig. 8. Comparison of Results Obtained with *S. oryza* Under Conditions of Sudden and Gradual Exposures

The time of the gradual exposure in these experiments was set arbitrarily at about one-sixth of the fatal exposure, and as no mortality occurred during that time the duration of this exposure might have been increased. It seems reasonable to assume that the decreased resistance of the weevils would be proportionate to the length of time

occupied in bringing them down to the low temperatures. This is supported by the fact, as shown in Figure 6, that loss of weight and consequently resistance occurs each day of dormancy.

Thus, the gradual approach of low temperatures which increases the resistance of hibernating insects and enables them to withstand the very low temperatures of winter, decreases the resistance of grain weevils and probably of the entire group of stored products insects.

The wheat in the culture from which these weevils were obtained had 16.4 per cent moisture. This gave the insects an increased resistance, as shown in the discussion of moisture, for it is noticeable that even with the decrease of resistance incurred by the gradual exposure, the percentage of mortality is much the same as that for weevils from a 13.2 per cent culture with a sudden decrease. This reveals the complexity of the study of resistance to low temperatures when the factor of moisture is considered, as it must be.

Cumulative injury and recovery.—In the discussion of dormancy and of the loss of weight during exposure to low temperatures, it was stated that as long as the grain weevils are dormant a continuous injury goes on which finally results in death. To determine if this cumulative injury is of a permanent nature or if it can be checked and overcome before death occurs, the following experiments were conducted. Weevils to the number of 15,614 were placed in the refrigerating cabinet at a temperature of —1.1° C. (30° F.) and exposed for 24 hours. During that period all suffered a loss of weight and an amount of injury was caused which resulted in a 32 per cent mortality.

With this definite injury against them, 4452 were taken out and placed in a culture of wheat having a moisture content of 19.7 per cent and standing at 22° C. (72° F.), room temperature. There, activity was shortly resumed. The remaining 11,162 were left in the refrigerator to determine how long it would require the accumulating injury to bring about death. This was found to be 96 hours. Those which had been transferred to the warm, moist wheat were left there for one week and then returned to the refrigerating cabinet. They had previously been exposed for 24 hours, or exactly one-quarter of the time required to kill them all, and had received injury to the extent of 32 per cent of the total mortality. Therefore it was possible, if the injury were permanent, that in an additional 72 hours all would be dead. It was found in this second exposure, however (Fig. 9), that they exceeded that period and went beyond the total span of the original expectancy, which was 96 hours. When the experiment ceased, 9 per cent were still active at 170 hours.

Thus it is seen that the injury received during dormancy, altho cumulative and eventually resulting in death, can be overcome by a

return to normal conditions. In addition, the original vigor of the weevils can even be increased if the new environment be a more favorable one.

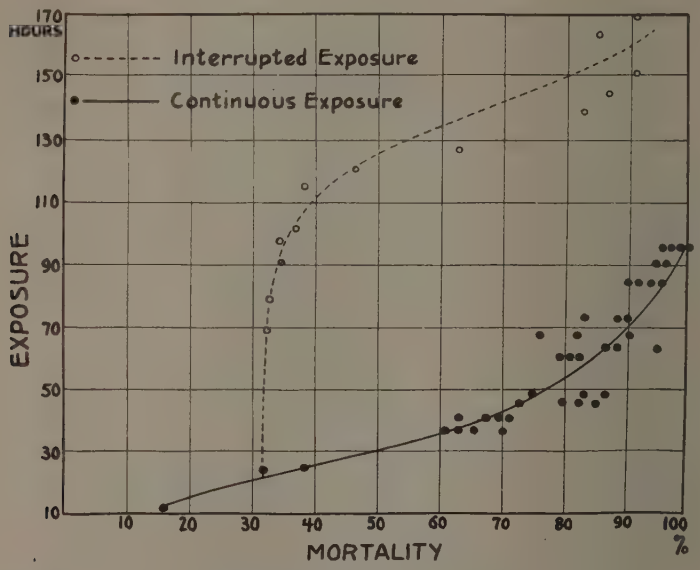


Fig. 9. Results of Interrupted and Continuous Exposures on *S. oryza*

MOISTURE

GRAIN WEEVILS AND THEIR MOISTURE PROBLEM

Moisture, which is necessary to the life of all organisms, is obtained in three ways: (1) directly, as in drinking; (2) through the food; (3) through metabolic changes within the organism. Such insects as stored products pests, which never have access to water directly, have to depend upon obtaining from the last two sources the amount of water needed.

The moisture content of grain varies somewhat, depending partly upon the variety and the degree of curing, also upon the amount of exposure to the air. Grain is affected by the amount of moisture in the air, giving off or taking on moisture until it comes into equilibrium with the surrounding atmosphere. The moisture content of stored wheat is probably between 10 and 18 per cent. This is a limited source of water when compared with the supply available to such insects as grasshoppers and aphids, which feed upon succulent plants containing from 60 to 90 per cent of water. With the former the problem appears to be the conservation, and with the latter the elimination, of

water. Thus, insects which live in stored grain, having access to very limited amounts of water and having adapted themselves to this condition, are affected by slight fluctuations in the moisture content of the grain.

PREVIOUS WORK ON THE RELATION OF GRAIN WEEVILS TO MOISTURE

Cole (1906) states that moisture in the atmosphere and in the food is favorable to both species of weevils and the lack of it is fatal. He does not, however, give precise data. One observation that "the rice weevil (*Calandra oryzae*) is distinctly less sensitive to desiccation than the corn weevil (*C. granaria*) and the former will live twice as long under the same conditions of desiccation as the latter" is not in accordance with the results of experiments conducted here.

Dendy (1918) studied the attractiveness of water in various containers placed in wheat, and concluded that both species are much attracted to moisture.

Dendy and Elkington (1920) found that when exposed to moist air wheat is more subject to attack by weevils than when kept dry. They also state that "very dry wheat is less liable to attack by weevils than wheat with a moderate or high moisture content." In addition, they showed that both species died when fed upon wheat having a moisture content of approximately 9 per cent.

EFFECT OF MOISTURE CONTENT OF WHEAT UPON MOISTURE CONTENT OF GRAIN WEEVILS

One of the earliest tests made here was to determine if the moisture content of the wheat in which the weevils live has any effect upon the moisture content of the body tissues of the weevils. Obviously, the amount of water in the wheat when eaten affects the moisture content of the weevils directly; and the amount of moisture in the grain affects the relative humidity of the air within the bin or container. This in turn influences the rate of elimination of moisture from the bodies of the weevils. It was therefore expected that moist grain would increase the moisture content of the weevils and that wheat containing less than the usual percentage of moisture would cause a corresponding decrease. However, as the experiments show, the opposite conditions were found to exist.

Ten samples of wheat containing (as shown in Tables IV and V) from 20.3 to 4.8 per cent moisture were prepared, and in these were placed a large number of weevils of each species. Readings of the moisture content of the weevils were made at intervals during the experiment, which lasted 30 days. These determinations were made

by the electric method described by the writer in Ecology, Vol. 7, No. 3, 1926. Briefly, it consists in impaling the insect upon a pair of fine electrodes set in a handle, as shown in Figure 10. When the electrodes penetrate the tissues a current of electricity is conducted to the poles and this causes a deflection within the galvanometer. It was shown by Zeleny (1909), when working on corn, and by the writer (1926) in his experiments on the moisture content of the tissues of living animals and growing plants, that the conductivity of the tissues is directly proportional to the amount of moisture present; so the magnitude of the deflection produced in the galvanometer when the electrodes



Fig. 10. Electrodes and Holder Used in Moisture Determinations

pierce the tissues indicates precisely the amount of moisture in these tissues. Therefore, by plotting a percentage scale of moisture for the species to be studied and placing this scale in the galvanometer, it is possible to read directly and quickly the percentage of moisture of the living tissues.

Tables IV and V show that the moisture content of both species of weevils was markedly affected by the moisture content of the wheat in which they live. These figures are averages obtained from 1000 separate moisture determinations. Every known precaution was observed in order to insure accuracy in making the determinations.

TABLE IV

Effect of Moisture Content of Wheat upon Moisture Content of *S. oryza*

Per cent moisture of wheat	20.3	17.5	14.0	12.5	8.2	7.9	7.0	5.5	5.3	4.8
	Per cent moisture of weevils									
Start	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8	64.8
3rd day	57.3	57.3	57.9	59.4	62.2	62.5	67.2	68.8	70.9	*
4th day	...	...	58.1	64.6	69.4	69.4	68.8	68.5	67.9	
5th day	57.0	60.6	61.3	60.2	68.7	68.8	71.2	*	*	
8th day	57.2	58.9	62.1	61.8	70.4	67.7	71.0			
12th day	57.9	59.6	60.8	66.0	*	*	*			
21st day	58.7	58.9	60.3	66.0						
30th day	58.5	60.0	62.7	66.1						
	†	†	†	†						

* Dead.
† Alive.

The results obtained were the reverse of what was at first expected: the weevils living in the moist grain had the lowest moisture content, and a decreased amount of moisture in the wheat caused an outstanding increase in the moisture content of the weevils. Apparently, the reason for this is that grain containing less than a certain percentage of water is unfavorable for the weevils and consequently the metabolic processes

of the weevils are disturbed. This causes an undue breaking down of such tissues as fats, and brings about an excess of carbon dioxide and water as by-products. Since these insects normally use small amounts of water, their power of elimination is probably proportionately limited. Therefore this excess moisture can not be given off as rapidly as produced and it accumulates within the body. Marked increases in the moisture content were followed in every case by death, and decreases by continued activity. The latter conditions were presumably more favorable than even the original stock culture.

TABLE V

EFFECT OF MOISTURE CONTENT OF WHEAT UPON MOISTURE CONTENT OF *S. granarius*

Per cent moisture of wheat	20.3	17.5	14.0	12.5	8.2	7.9	7.0	5.5	4.8
	Per cent moisture of weevils								
Start	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2	67.2
3rd day	58.5	58.5	58.0	58.5	62.8	64.4	67.6	69.3	70.5
5th day	58.9	59.5	61.5	61.3	65.1	67.2	67.6	71.8	71.4
8th day	58.7	59.5	60.6	61.4	66.0	66.0	67.6	72.5	*
12th day	58.9	60.6	61.6	62.5	66.3	66.9	71.4	76.9	
21st day	58.6	60.0	61.2	61.6	66.7	67.2	71.4	*	
30th day	59.1	60.2	61.5	63.0	67.9	71.4	*		
	†	†	†	†	†	*			

* Dead.
† Alive.

EFFECT OF MOISTURE CONTENT OF WHEAT UPON WEIGHT OF WEEVILS

In order to determine if the moisture content of the wheat would affect the weight of the grain weevils as it had affected their moisture content, the following experiments were conducted: Two samples each of wheat of 20.3, 14.0, 12.5, 8.2, and 7.0 per cent moisture were prepared, and in each were placed 50 weevils of either species which had just been weighed. At intervals of 2, 4, 6, and 19 days the weevils were taken out of the wheat and weighed, with results as shown in Tables VI and VII. Each time the weevils were removed from their containers a fresh supply of wheat of a similar moisture content was substituted.

TABLE VI

EFFECT OF MOISTURE CONTENT OF WHEAT UPON WEIGHT OF *S. oryza*

Per cent moisture of wheat	20.3	14.0	12.5	8.2	7.0
	Per cent weight of weevils				
Start	100	100	100	100	100
2nd day	102.5	101.2	97.3	93.1	87.9
4th day	105.0	101.2	94.7	84.9	79.2
6th day	105.0	101.2	89.4	73.9	63.4
19th day	105.0	103.8	*	*	*

* Dead.

With the higher percentages of moisture, namely, 20.3 and 14.0 per cent, the weight of both species, but especially of *oryza,* was not only maintained but actually increased. With the lower amounts of moisture, however, both species continued to lose weight until some individuals died when the experiments were terminated. The decrease in weight took place more rapidly with *oryza* than with *granarius.*

TABLE VII

EFFECT OF MOISTURE CONTENT OF WHEAT UPON WEIGHT OF *S. granarius*

Per cent moisture of wheat	20.3	14.0	12.5	8.2	7.0
	Per cent weight of weevils				
Start	100	100	100	100	100
2nd day	101.5	100.6	98.4	96.4	92.5
4th day	102.3	101.3	95.4	94.2	89.1
6th day	102.3	101.3	92.3	91.3	86.3
19th day	103.9	102.0	88.5	*	*

* Dead.

Davenport (1897) states "Water plays a part in growth second in importance to no other agent, so that in its absence growth cannot occur. As the quantity is increased, growth is increased until an optimum is reached. The amount imbibed does not, however, depend directly upon the amount available, but rather upon the needs and habits of the species."

For the decrease in weight an explanation is offered in the discussion of the previous experiment. The cause of the increase in weight can possibly be arrived at by reversing the order of reasoning. The fats which there were broken down are here built up. There, excess water was produced; here, the presence of additional water in the wheat provides the extra water necessary in building up the fats. Babcock (1912) states ". . . one hundred parts of cellulose or starch, $(C_6H_{10}O_5)_n$, containing 6.17 per cent of hydrogen, gives 55.5 parts of water; one hundred parts of anhydrous dextrose containing 6.66 per cent of hydrogen gives 60 parts of water, etc. Most of the fats yield more than their weight of water, while proteins, when completely oxidized, give from 60 to 65 per cent of water." Thus, on the one hand there is loss of weight through consumption of reserve tissues, and on the other hand gain in weight by the storing up of additional tissues.

FLUCTUATIONS IN MOISTURE CONTENT OF WHEAT AND RESPONSIVE CHANGES IN WEIGHT AND MOISTURE CONTENT OF GRAIN WEEVILS

It has been shown that a change in the moisture content of the wheat will cause a change in both moisture content and weight of the weevils. Further tests were made on the possibility of repeated fluctuations bringing about corresponding responses on the part of the weevils. Accordingly, 200 granary weevils were taken from the stock culture of 13.5 per cent moisture content and transferred first to wheat of 20 per cent moisture for 3 days, then put in 5.3 per cent wheat for 4 days; returned to 20 per cent wheat for 3 days, and once more put into 5.3 per cent wheat. The same procedure was used for the rice weevils except that the dried wheat contained 8.4 per cent moisture, 5.3 per cent being too low.

Several readings were taken each time before changing the wheat and the averages of these readings are plotted on charts in Figures 11 and 12. It can be seen that the moisture content of each species not only varied inversely with that of the wheat upon which they fed, as previously found, but that this continued as long as the changes were made.

For the study of the effect on weights, treatment similar to that described for moisture was adopted, and weights were taken at the time each transfer was made. In these experiments a direct variation in weight appeared, as in previous experiments, in response to fluctuations in moisture content of wheat; and these variations up and down continued as long as the changes were made. It is noteworthy that the largest amount of fluctuation in both weight and moisture content was always caused by the dry wheat, and that *oryza* was more affected than *granarius*.

The rapidity with which each species reacted to the varying conditions is another outstanding feature. Further experiments might show that these intervals could be still further shortened. Also the number of times that the weevils will react to varying moisture content of wheat might be extended, as each species was still active at the end of the series of experiments.

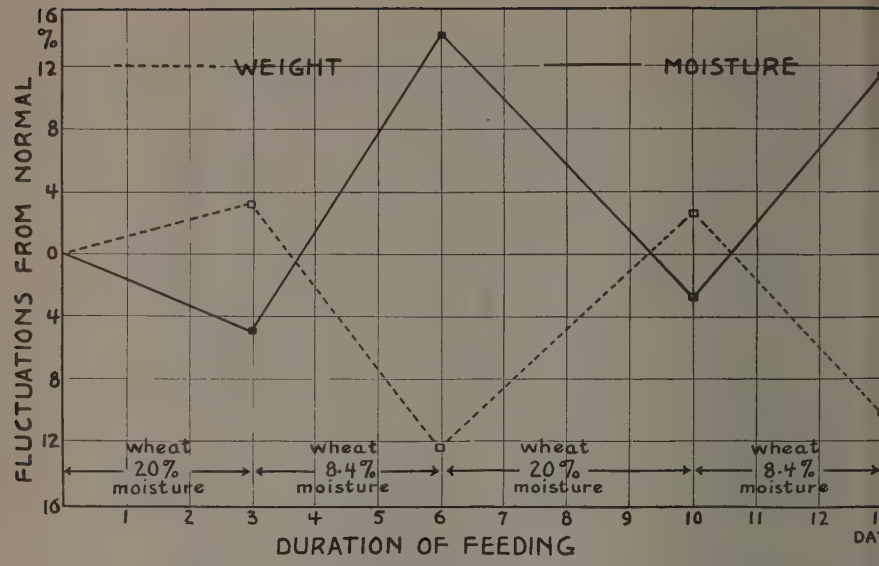


Fig. 11. Fluctuations in Weight and Moisture Content of *S. oryza* Following Changes in Moisture Content of Wheat

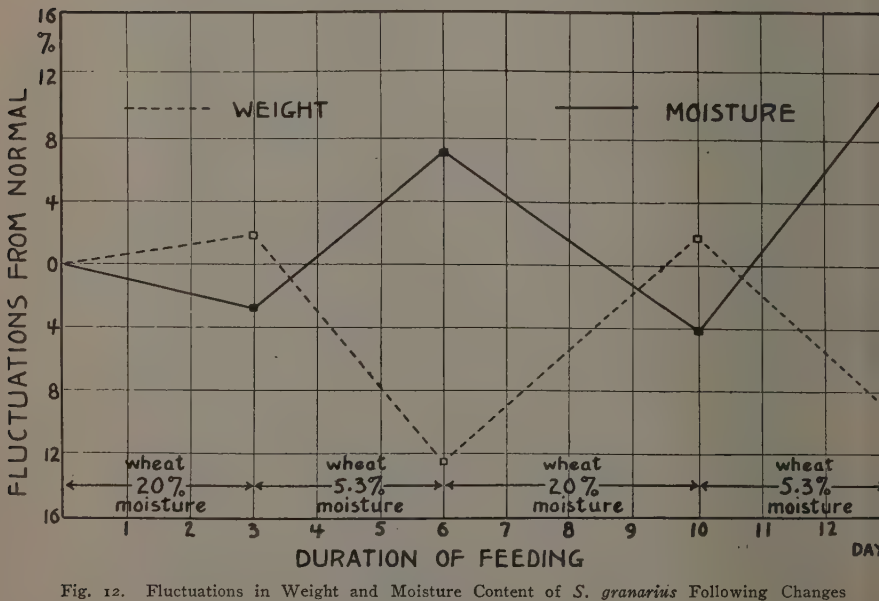


Fig. 12. Fluctuations in Weight and Moisture Content of *S. granarius* Following Changes in Moisture Content of Wheat

EFFECT OF MOISTURE CONTENT OF WHEAT ON FREEZING POINT OF GRAIN WEEVILS

In Tables IV and V is shown an inverse variation in the moisture content of the weevils with that of the wheat upon which they fed. This was exactly the opposite of what at first was expected, and required not only an explanation but, if possible, additional confirmation of the accuracy of the data.

An increase in the moisture content of the weevils would bring about a greater dilution of their body liquids; and a decrease in the amount of moisture would cause a greater concentration of their liquids. This would result in a corresponding change in the freezing point of their tissues: an increase in the moisture content would raise the freezing point and a decrease would lower it; so that, by determining the freezing point of a number of weevils taken from wheat of various moisture contents, the accuracy of the data showing an inverse variation in the moisture content of the grain weevils with that of the grain would be either confirmed or refuted.

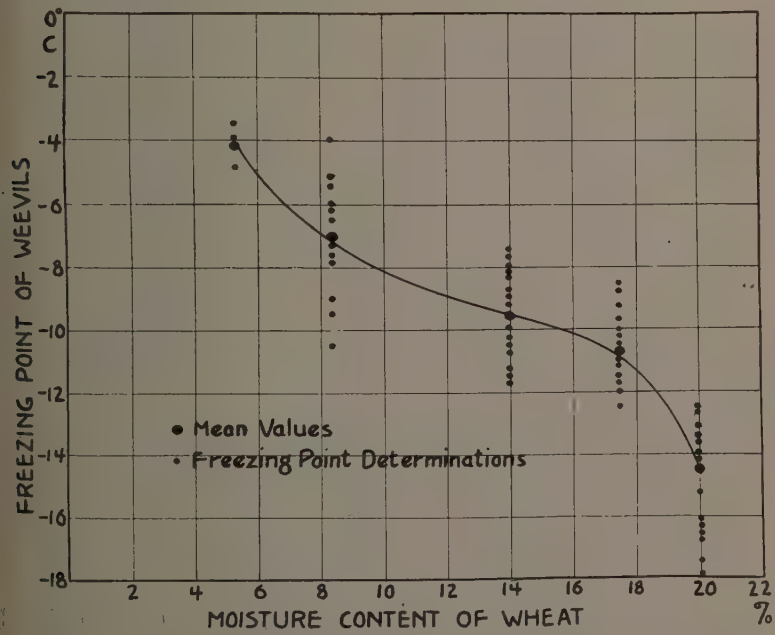


Fig. 13. Correlation of Moisture Content of Wheat and Freezing Point of Weevils

Accordingly, 75 freezing point determinations were made with insects taken from wheat of different moisture contents by means of an electric thermocouple. Results, as charted in Figure 13, show that

weevils living in dried wheat have a high freezing point and that by increasing the moisture content of the wheat the freezing point of the weevils living in it is lowered. These experiments, therefore, confirm the accuracy of the data in question.

In every instance the weevils failed to survive these freezing point determinations. Grain weevils, however, commonly endure for a short period temperatures as low as those at which freezing occurs. Therefore death apparently was caused by the lowering of the temperature below the freezing point to the undercooling point where the heat of crystallization is liberated, with the resulting rebound from the undercooling to the freezing point as described by Bachmetjew (1901).

It follows from these results that another disadvantage accrues to grain weevils in dry wheat. It is shown in the treatise that with dry wheat their mortality is increased and resistance to low temperature decreased, while here it is seen that their freezing point is raised. These conditions are detrimental to the weevils and increase their hazard of life.

OPTIMUM, MAXIMUM, AND MINIMUM MOISTURE CONTENT OF WHEAT REQUIRED BY GRAIN WEEVILS

Since the moisture content of the wheat has a marked effect upon the moisture content and weight of the weevils, the question arose as to what percentage of moisture would be most favorable; also how much and how little could be endured.

Samples of wheat with moisture content varying from 20.3 to 4.8 per cent, as shown in Tables VII and VIII, were prepared and 50 weevils of either species were placed in the containers—tin boxes 3 inches in diameter and 1½ inches high, with closely fitting lids. At the time of taking each count of the number of weevils living, the contents of the box were spread on a piece of white paper. The weevils usually feigned death at first but they were allowed 15 minutes to recover and move away. The active ones were then put back in the box with a fresh supply of wheat of the same moisture content.

TABLE VII

EFFECT OF MOISTURE CONTENT OF WHEAT UPON MORTALITY OF *S. oryza*

Per cent of moisture of wheat	20.3	17.5	14.0	12.5	8.2	7.9	7.0	5.5	5.3	4.8
	No. of living weevils									
Start	50	50	50	50	50	50	50	50	50	50
6th day	50	50	49	47	27	18	14	12	11	2
13th day	50	49	48	46	6	7		3		
23rd day	50	49	46	40	5					
38th day	50	49	46	39						

TABLE VIII

EFFECT OF MOISTURE CONTENT OF WHEAT UPON MORTALITY OF *S. granarius*

Per cent of moisture of wheat	20.3	17.5	14.0	12.5	8.2	7.9	7.0	5.5	5.3	4.8
	No. of living weevils									
Start	50	50	50	50	50	50	50	50	50	50
6th day	50	50	49	47	47	38	41	42	40	41
13th day	50	50	47	44	29	27	25	28	25	16
23rd day	50	49	47	44	27	20	16	18	16	4
38th day	50	49	47	44	13	4				

Results of the counts taken at intervals over 38 days show that neither species can endure a moisture content of below 8.2 per cent, and that about 14 per cent is probably necessary for *oryza*, while *granarius* can probably exist upon 12.5 per cent or slightly less. The comparatively high moisture content required by *oryza* and the lower amount which can be tolerated by *granarius* are possibly the explanation of the observation made by Dendy and Elkington (1920) that nearly all the adults of *S. oryza* kept indoors at ordinary laboratory temperatures were killed during the winter, while the adults of *S. granarius* survived the winter in large numbers. Wheat exposed in the laboratory here in Minnesota during the winter has been found to decrease in moisture from 14.0 to 8.0 per cent owing to the dryness of the atmosphere, which sometimes has a relative humidity as low as 15.0 per cent in winter. Dendy and Elkington attribute this mortality to temperature. However, unless long periods of temperature as low as 46° to 48° F. were included as being among the ordinary laboratory temperatures, it is improbable that the mortality was due to temperature, for the minimum effective temperature of *oryza* has been shown to be 46° to 48° F.

With regard to the optimum moisture requirements of grain weevils, if the criterion be that in which the least mortality occurred, it would be between 17.5 and 20 per cent. However, wheat having such a high percentage of moisture is inclined to heat, and it appears questionable whether the grain weevils, down through the centuries in which they have been known as pests of stored grain, have for their optimum a condition which is so seldom found in grain. It seems more likely that they have become adjusted through countless generations to a moisture content which most generally occurs and which is between 12 and 16 per cent.

In regard to the maximum amount of moisture which the weevils can endure in wheat, it is obvious that the study of the behavior of the weevils in grain of 25, 30, and 35 per cent moisture is mostly a matter of interest, for such high moisture content rarely, if ever, occurs

in stored wheat. Nevertheless, a few tests were made on very moist wheat and it was found that the maximum amount of moisture which the weevils can endure is not limited directly by the actual amount present, but by a complication which sets in under such conditions. When wheat was raised to 30 and 35 per cent moisture, the temperature increased from 72° to 79° F. in 4 hours, and the thousands of weevils which had been placed in the wheat all came to the surface and seemed much disturbed. This uneasiness could not have been due to the increased temperature, which was not at all excessive, but supposedly was due to the large quantity of CO_2 given off within the mass of wheat. Bailey and Gurjar (1918) prepared a chart showing that an increase in the moisture content of wheat above 15 per cent caused an enormous acceleration in the amount of CO_2 produced, owing to the increased rate of respiration of the wheat. The weevils remained chiefly upon the surface of the wheat for 4 days, during which time they went down into the mass for periods of about an hour but invariably returned to the surface and roamed around restlessly and died within a week.

ATTRACTIVENESS OF WHEAT HAVING VARIOUS PERCENTAGES OF MOISTURE

If samples of wheat varying between the two extremes of moisture were available to the weevils, would they select that which presented the most favorable conditions for them? To determine this, eight glass tubes 8 inches long and 1½ inches in diameter were marked on the outside into divisions numbered from 1 to 10. Into these divisions were placed samples of wheat as shown in Table IX.

TABLE IX

Moisture Content of Samples of Wheat Used in Tubes

Divisions	Moisture, %
1	4.8
2	5.3
3	5.5
4	7.0
5	7.9
6	8.2
7	12.5
8	14.0
9	17.5
10	20.3

When the divisions were half filled, 200 rice weevils were placed in each of four tubes and 200 granary weevils in each of the other four tubes. Then the remainder of each tube was filled. Thus the insects were centrally located and were at liberty to move in the direction to which they were attracted.

Corks were used in the ends of each tube, one having a 5/16-inch hole screened with wire gauze and the other being solid. The whole cork was placed in the moist end in half of the tubes and in the dry end in the other half. The tubes were then placed horizontally, away from the light, where they were left undisturbed, except for daily inspection, for 30 days.

The actual number of insects in each compartment of the tube could not be counted, as most of them were out of sight among the grain, but the light-colored excrement which always accumulates where these insects feed fell through the wheat to the lower side of the tube and thus revealed their presence. From the first day to the end of the experiment weevils lived only in sections 7 to 10, the greatest amount of excrement being found in No. 10 and grading down very noticeably to but little in No. 7. None ever fed in sections 1 to 6 and apparently they were repelled from that part of the tube, for no indication of their presence occurred at any time.

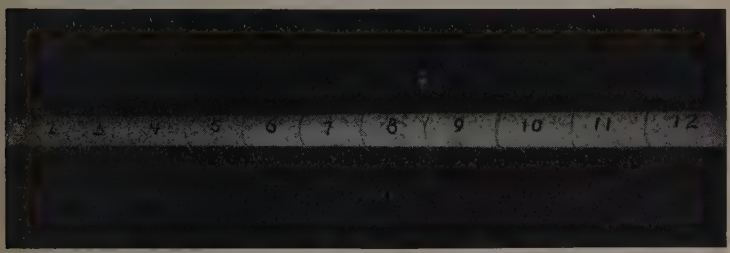


Fig. 14. Under Side of Tube Showing Graded Accumulation of Whitish Feces, Which Indicates Presence of Weevils

These experiments were repeated with a tube 24 inches long, with a view to increasing the distance apart of the two extremes and thus making it more difficult for the weevils to find their optimum. The divisions were increased to 12 by adding wheat of 25 and 30 per cent moisture, but in other respects it was treated the same as the previous tubes. The results were identical with those of the other experiments, a marked and early preference being shown for the moist wheat.

Figure 14 shows the condition of a tube at the end of three weeks. The weevils were left in the wheat for two months, during which time the moist wheat became moldy and then turned dark and began to decay, giving off a very offensive odor. Nevertheless, some weevils continued to live there. When the tube was emptied, the majority of the weevils were found in or near section 9, which contained wheat of 17.5 per cent moisture.

DRY WHEAT AND MORTALITY OF WEEVILS

Some data were needed on the cause of weevils being repelled from dry wheat and attracted to moist grain. The drier the wheat the harder becomes the seedcoat, and conversely, the more moist the grain the softer is its covering. Hard, dry grain is more difficult to penetrate in order to obtain food, and this mechanical difficulty probably aids in making dry wheat unfavorable and moist wheat attractive.

If the hardness of the grain covering, however, were the only factor involved, this could be discovered by using broken wheat. A series of experiments, therefore, was run in which dry grain of 8.2 and 4.8 per cent was used, and in half the experiments the wheat was left whole while in the other half it was well broken up. Check experiments having normal wheat of 13.2 per cent moisture and others in which no food at all was used, were run at the same time. One hundred weevils were placed in each container and the numbers were counted at intervals for twenty days.

The results are charted in Figures 15 and 16 and show that with *oryza* the death rate was practically identical in both whole and broken wheat of 4.8 per cent and all the weevils died within five days. This was one day earlier than where no food was provided, and the probable explanation is that the dry wheat lowered the relative humidity of the air in these containers and hastened death. In the whole wheat of 8.2 per cent moisture, death was retarded until the eleventh day, while in the broken wheat of similar moisture content 85 per cent of the

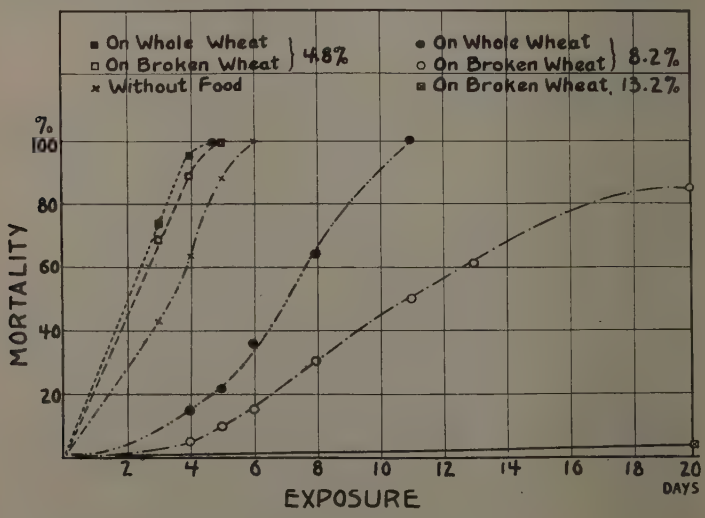


Fig. 15. Comparative Effect of Whole and Broken Dried Wheat on Mortality of *S. oryza*

weevils were killed in twenty days. The checks which lived in the 13.2 per cent wheat suffered only 2 per cent mortality. *Granarius* was able to endure the low moisture content of the experiments longer, and here, also, there is a slight advantage in favor of the broken wheat.

In all the experiments in which dried wheat was used, the rate of mortality increased each day whether the wheat was whole or broken, and it is evident that death was not due to the hardness of the pericarp and the consequent difficulty of obtaining food. It is more likely that death (preceded by loss of weight, as shown in Table VI and VII) was due to water deficiency. Jackson (1925) on pages 14-16, cites the work of several experimenters who found death to occur in various animals as a result of being fed on dry foods for certain periods. The importance of water in the metabolic processes has been emphasized by many workers. The living organisms require a large and fairly regular amount of water, and if this is lacking the body breaks down its reserve tissues to supply the water necessary. It was stated by Lorenzen (1887), as cited by Jackson (1925), that "a relatively dry diet is very effective in reducing the amount of fat in man, a principle used in the reducing diet by Oertel and others."

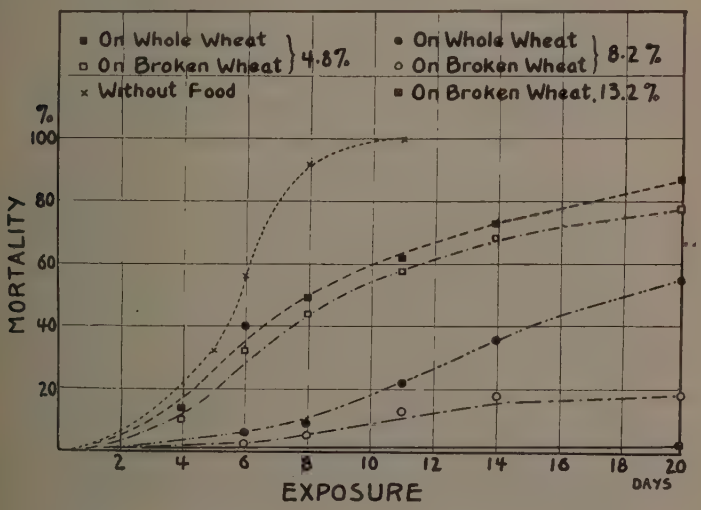


Fig. 16. Comparative Effect of Whole and Broken Dried Wheat upon Mortality of *S. granarius*

Pratje (1921) is quoted by Jackson (1925) as follows: "Pratje ('21) has recently made an extensive and careful study of the changes found in *Noctiluca miliaris* kept without food and observed alive. The normal fat-droplets disappear gradually (in eight to fourteen days), so that the cytoplasm becomes transparent. The central cytoplasmic mass

is greatly reduced in amount, with fewer and thinner radial extensions to the periphery. There is a corresponding increase in the peripheral vacuolar fluid, however, so there is no appreciable decrease in the size of the whole cell. The nucleus becomes more distinctly visible and more transparent. The nucleoli often become visible. Thus far only the more fluid endoplasm has been affected, but as inanition progresses, the firmer, peripheral protoplasmic structures (cell membrane and organs) are attacked and consumed. In about three weeks, all available sources of energy are exhausted. Recovery by refeeding is now impossible, and death soon occurs."

Berger (1907) fed the larvae of the mealworm, *Tenebrio molitor,* on dried bran for a time and found that their weight decreased each day until death occurred. He also found the moisture content of these insects to remain nearly constant, altho they lost weight until death occurred.

Bodine (1921), when working with certain species of grasshoppers, found that death from starvation could be deferred for about twice the length of time if water were supplied.

It therefore seems probable that in these experiments death was due to the breaking down of such tissues as fats to supply the required amount of moisture. This, the results of the previous experiments tend to confirm.

EFFECT OF EXPOSURE TO LOW TEMPERATURE UPON MOISTURE CONTENT OF GRAIN WEEVILS

In the daily study of the moisture content of the weevils during the course of exposure to low temperatures, a marked disturbance of their metabolic processes is revealed by the fact that during the first few days of dormancy a very rapid rise in moisture content takes place, followed by an equally rapid decline, as shown in Figure 17. In addition, a check series was run in which both species were allowed to starve at a room temperature of 72° F. (Fig. 18). With *oryza* death occurred in every instance while they had an abnormally high percentage of moisture, which proves that death from low temperatures is not caused by loss of moisture. *Granarius* were still alive after their moisture content had returned to normal; and the long, gradual decrease of moisture which preceded death does not indicate that death was caused by loss of water, for even at the time of death the amount of moisture present was identical with the amount commonly found in weevils when living under the most favorable conditions.

The fluctuations in moisture content during exposure to low temperatures may be considered along with two other occurrences, namely, the continuous loss of weight which has been shown to occur, and the death of the insects, which is inevitable if dormancy continues. It

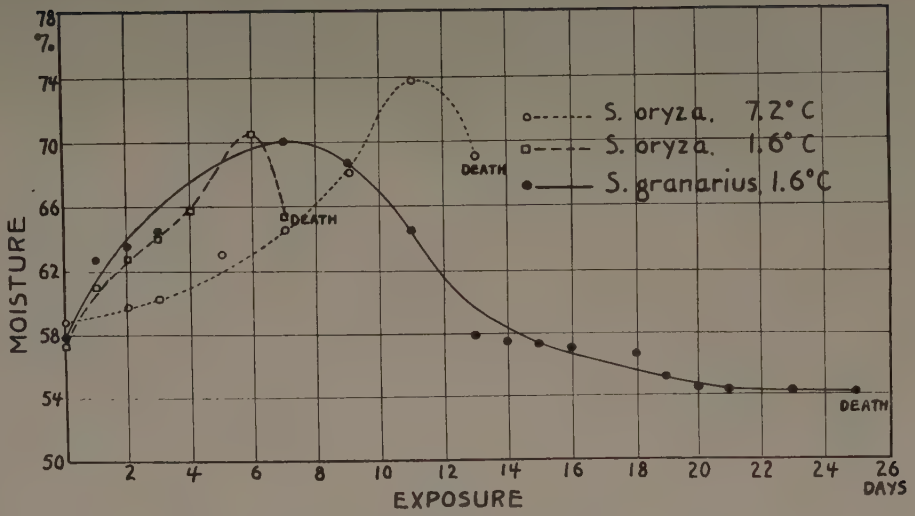


Fig. 17. Disturbing Effect of Moderately Low Temperatures upon Moisture Content of Dormant Weevils

appeared earlier that these insects have never learned to adapt themselves to low temperatures and that their metabolic processes are probably not reduced in velocity to the very low rate characteristic of hibernating insects when in the state of dormancy. Thus, there are on the one hand the active metabolic processes which require a supply of oxidizable organic material, and on the other hand the inability of the insects, being dormant, to feed themselves. Metabolism therefore is maintained at the expense of such reserve tissues as fats, stored in the body. This accounts for the continuous loss of weight. Carbon dioxide and large amounts of water are formed as by-products; and

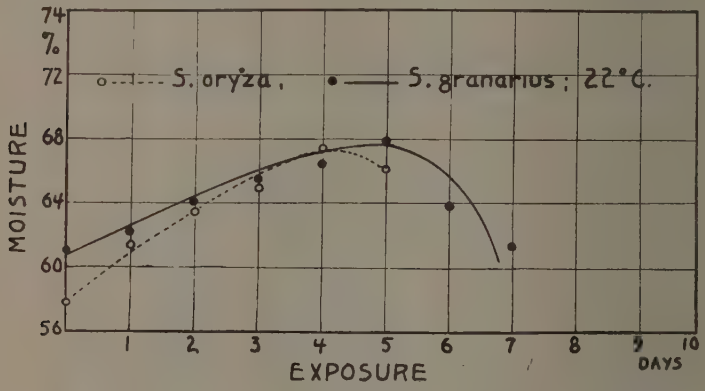


Fig. 18. Rise in Moisture Content of Active Weevils During Starvation and Decline with Approaching Death

since these insects live in grain which seldom contains more than from 12 to 16 per cent moisture, their capacity to eliminate water is probably very limited, and the excessive amount of water which results from the oxidation of fats accumulates within the body and causes the high moisture readings which are so outstanding in this work.

EFFECT OF MOISTURE CONTENT OF WHEAT ON RESISTANCE OF GRAIN WEEVILS TO LOW TEMPERATURE

Some data have thus far been accumulated regarding the effect upon moisture content and weight of grain weevils of two factors, viz., the moisture content of their food and exposure to low temperatures; and some hypotheses have been offered to account for what has happened. Meager as the facts are likely to be, they appear to fit together and each helps to make more intelligible some of the phenomena associated with it. In addition, it has been possible, with the data already acquired, to prove by experimentation that the moisture content of the wheat affects the ability of the weevils to resist exposure to low temperatures.

A large number of weevils of each species were placed in wheat of different moisture content and allowed to feed there for about three weeks. They were then removed, along with a check series from wheat of normal moisture, to the refrigerating cabinet and exposed to a given low temperature. In every instance the moisture content of the wheat had a definite effect upon the cold-resistance of the weevils.

Figure 19 shows the results of 58 experiments with 9931 granary weevils. The resistance of those which had lived in wheat of 17.2 per cent moisture was so greatly increased that, for instance, an exposure of from 20 to 40 hours to —12.2° C. (20° F.) caused only 10 per cent mortality, while those which had fed upon wheat of 13.1 per cent moisture suffered a mortality as high as 80 per cent.

With the rice weevils a more extended series was conducted in which the temperature was —1.1° C. (30° F.).

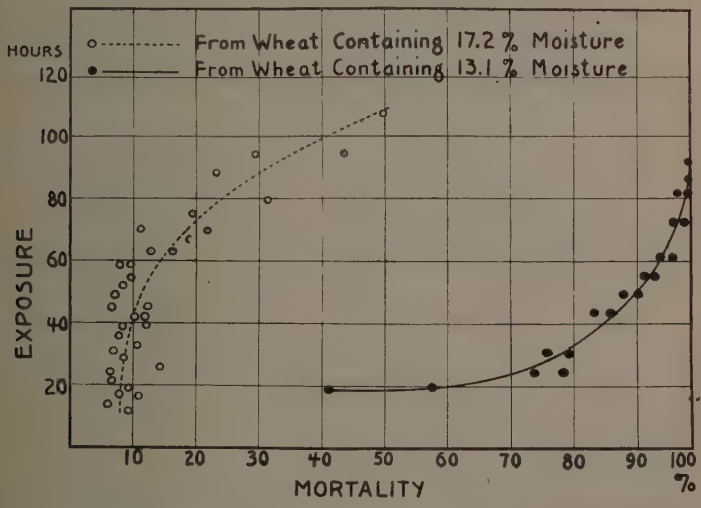


Fig. 19. Comparative Resistance of *S. granarius* to —12.2° C. (10° F.) When Fed on Moist and Normal Wheat

Figure 20 shows that with a decrease or increase in the moisture content there is a corresponding decrease or increase in the resistance of the weevils to low temperatures.

An additional fact came out of this experiment, namely, the correlation of the moisture content of wheat and the time required to obtain 100 per cent mortality takes the form of practically a straight line, as in Figure 21. From this it appears possible, when knowing the moisture content of the wheat, to predict the time required to kill; and conversely, having established the length of exposure necessary to kill, the percentage of moisture of the wheat could be determined.

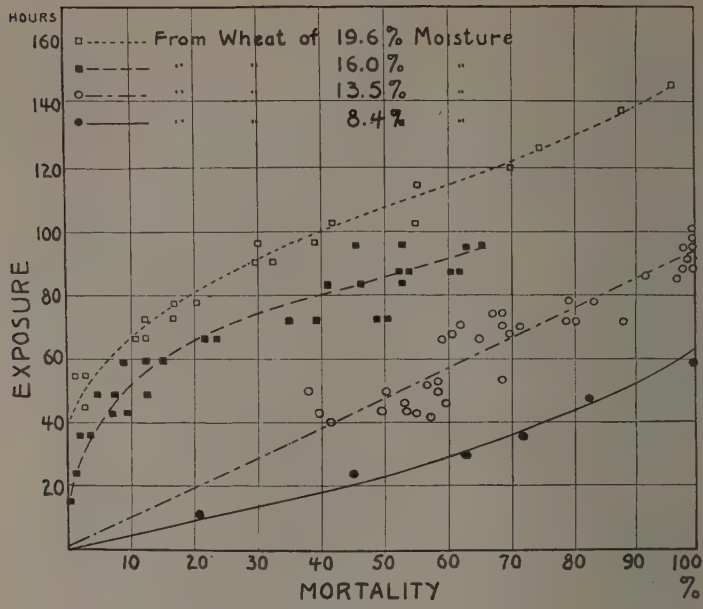


Fig. 20. Comparative Resistance of *S. oryza* to —1.1° C. (30° F.) when Fed on Wheat of Various Moisture Contents

Moisture of wheat, per cent	No. of experiments	No. of individuals
19.6	20	6,007
16.0	32	8,941
13.5	51	11,362
8.4	6	1,194
	109	27,504

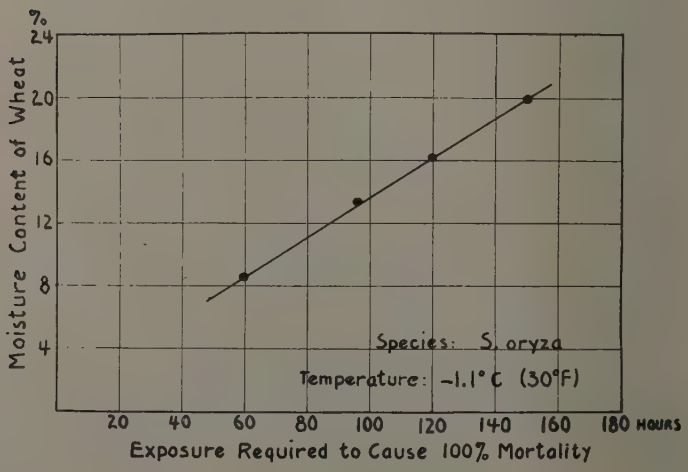


Fig. 21. Correlation of Moisture Content of Wheat and Length of Exposure Required to Kill Grain Weevils

COMPARATIVE MOISTURE-RETAINING CAPACITY OF GRAIN WEEVILS

It is characteristic of *oryza* to be much more susceptible than *granarius* to fluctuations in the moisture content of its food. This susceptiblity is accompanied by a high mortality if the moisture content is reduced to less than its normal requirements. This might be due to the greater loss of moisture which occurs with this species, partly due no doubt to the evaporation of a greater amount of moisture from its surface. A thinner or a more porous integument, or the presence of larger spiracles would facilitate the exudation of moisture; and being a smaller species, *oryza* has a greater amount of surface to mass. A morphological study of the structure of these insects is beyond the scope of the present study, and other means were adopted with a view to determining the comparative rate of moisture loss.

This was done by studying the rate at which the moisture decreased during desiccation. A large number of weevils of each species were obtained and moisture determinations taken; then they were chloroformed so that death would be simultaneous. Subsequent determinations were made until the weevils became dry.

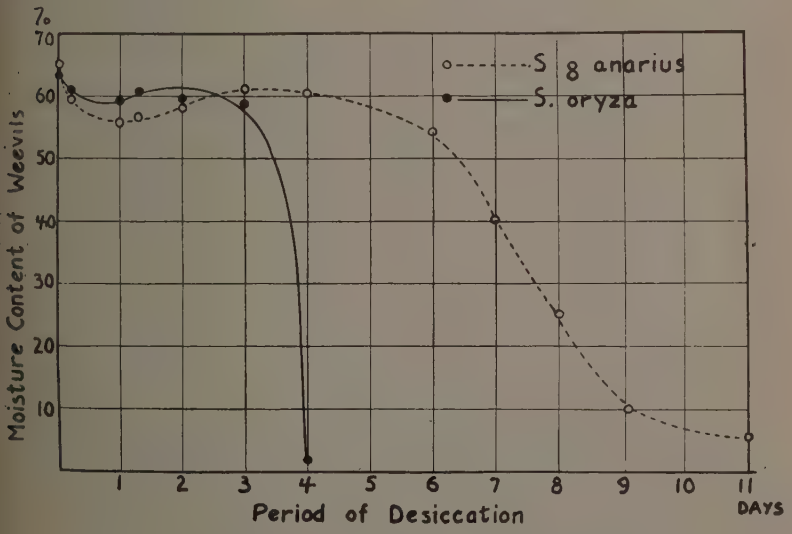


Fig. 22. Comparative Rate of Drying Out of Tissues after Death

As usual, *oryza* lost its moisture rapidly, and became entirely dry in 4 days; while *granarius* retained moisture for 11 days. A study of Figure 22 will show this relation. The very rapid descent in moisture during the first three hours is doubtless due to the desiccating effect of the chloroform upon the tissues. With the evaporation of the chloro-

form, the moisture content rose again somewhat, but not to the original amount. The absence of the rise in moisture which is shown in Figures 17 and 18 is noteworthy and may be attributed to the cessation of the metabolic processes after death.

EFFECT OF WEEVIL INFESTATION UPON MOISTURE CONTENT OF WHEAT

Having found that the moisture content of the wheat materially affects the moisture content of the weevils' tissues, it was then to be determined if the reverse of this occurs. The present experiment was planned to discover if the moisture content of the grain was affected by the presence of weevils living and feeding within its mass.

Thirteen bottles were each filled with 1000 grams of wheat having a moisture content of 13.5 per cent. In each of 12 bottles, 1000 weevils were placed (6 bottles for each of the two species) and the 13th was left uninfested to serve as a check. These bottles were allowed to stand undisturbed for two months, when the weevils were removed and determinations were made of the moisture content of the wheat. These determinations showed that the granary weevil had raised the moisture content to 17.3 per cent and the rice weevil to 18.0 per cent while the wheat in the check or uninfested bottle decreased to 13.1 per cent, owing to drying out in the laboratory.

This shows that the grain weevils are able to initiate a rise in the moisture content of the wheat, despite the dry atmosphere of the laboratory. The assumption is that this was done through the elimination of moisture produced during the process of respiration, not necessarily the respiration of the weevils only, but also of the wheat. Back and Cotton (1924) state that the temperature of grain is frequently raised when a large number of weevils collect together in the mass of grain, and that this must be due to the activities of the insects themselves for it can be lowered by fumigation. Phillips and Demuth (1914) observed that clusters of bees will raise the temperature to 95° F. within the hive when the outside temperature is 32° F.

With this increase in temperature of the grain by the presence of weevils there occurs an acceleration of respiration of the wheat as shown by Bailey and Gurjar (1918), and this in turn gives off carbon dioxide and water. Therefore it seems probable that part of the increase in moisture content of the wheat results directly from the respiration of the wheat itself.

The fact of the increase of moisture content of wheat by the presence of weevils is of more than passing interest for it has an important corollary, viz., it brings about a series of conditions which are all more favorable for the weevils themselves. These are:

(1) The moisture content of the wheat is raised to one which these experiments show to be more favorable in prolonging the life of the weevils.

(2) The weight of the weevils is increased, which implies a greater amount of reserve tissue such as fats being formed and a correspondingly greater protection from starvation.

(3) Resistance to low temperatures is greatly increased. In this particular case it was increased over 200 per cent, for the weevils used in the experiment charted in Figure 19 were obtained from the identical culture that was raised from 13.5 to 17.7 per cent through metabolic water.

(4) The freezing point of the insect tissue is lowered.

(5) Sexual activity is stimulated in the higher moisture contents.

(6) The temperature is raised following an increased moisture content to one more favorable for development. Bailey and Gurjar (1918) show that biological oxidation of the wheat through the action of oxidizing enzymes is accelerated by increased moisture, and this raises the temperature of the grain.

The temperature of a culture of rice weevils in a north room away from direct rays of the sun was taken for 12 days during the month of September, and when compared with the temperature of the room air close by the tank showed an increase in every case, as follows:

TABLE X

Comparison of Temperatures of Laboratory and Culture of Rice Weevils

Date	Laboratory	Culture
	° C.	° C.
September 16.....	22.5	31.0
17.....	27.0	34.5
19.....	24.3	32.0
21.....	17.0	27.5
23.....	19.2	27.0
24.....	21.5	31.2
28.....	20.5	30.2
Average.....	21.7	30.2

It therefore appears that if these insects can once become established they will not only maintain themselves but will continue to improve their condition. An obvious disadvantage lies in the fact that with a limited food supply the saturation point, followed by death, is reached more quickly.

TEMPERATURES OF GRAIN STORED IN TERMINAL ELEVATORS, WITH THE SUGGESTION OF A POSSIBLE MEANS OF CONTROLLING GRAIN WEEVILS

Experiments in the laboratory show that grain weevils are killed by exposure to temperature as high as 45° F. for *oryza* and 35° F. for *granarius*. It follows from this that if the temperature of grain in storage is reduced to that degree and held there long enough, the weevils infesting the grain will be destroyed.

A preliminary study of the temperatures of grain in elevators was made from records supplied by one of the elevator companies of Minneapolis, whose tanks are equipped with a thermocouple system which registers the temperature of the mass of grain every five feet up the tank. Records of the temperature were taken weekly throughout the year.

These temperatures were plotted for the year and one of the charts is shown in Figure 23. This chart can be divided into three sections. In the first part the temperatures are increasing in the upper part of the tank and in this section occurs the greatest spread between the highest and lowest temperatures, the lowest being 37° F. and the highest 85° F. Such a high temperature as the latter indicates that the wheat is getting into a dangerous condition, one remedy for which is overturning, so about November 24, when the outdoor mean temperature was 35° F., the wheat was turned from tank 7 to tank 12. This reduced the temperatures to 40° F. for the lowest and 65° F. for the highest, and diminished the range to 25° instead of 48° F. as before the overturning. It is thus seen that the overturning caused a general decrease in temperature of the wheat throughout the tank.

In the third section is seen the effect of an additional overturning when advantage was taken of a drop in the outside temperature to lower the temperature of the wheat still further in order to carry it over the coming summer. The lowest and the highest temperatures are still further reduced to 35° and 54° F. respectively, with a range of 21° F. In the upper 20 feet of the tank the temperatures are low enough to kill both species of weevils. It is very probable that if an additional overturning or two had been made during January, when the outside temperatures were down to 0° F., the temperatures of the grain within the tank would all have been lowered to about 35° F., and in such a temperature no weevils could remain alive for more than a month. This wheat, being free of infestation, could be gradually raised in temperature by additional overturnings in early spring to avoid the "sweating" which occurs when cold wheat is exposed to the air in summer.

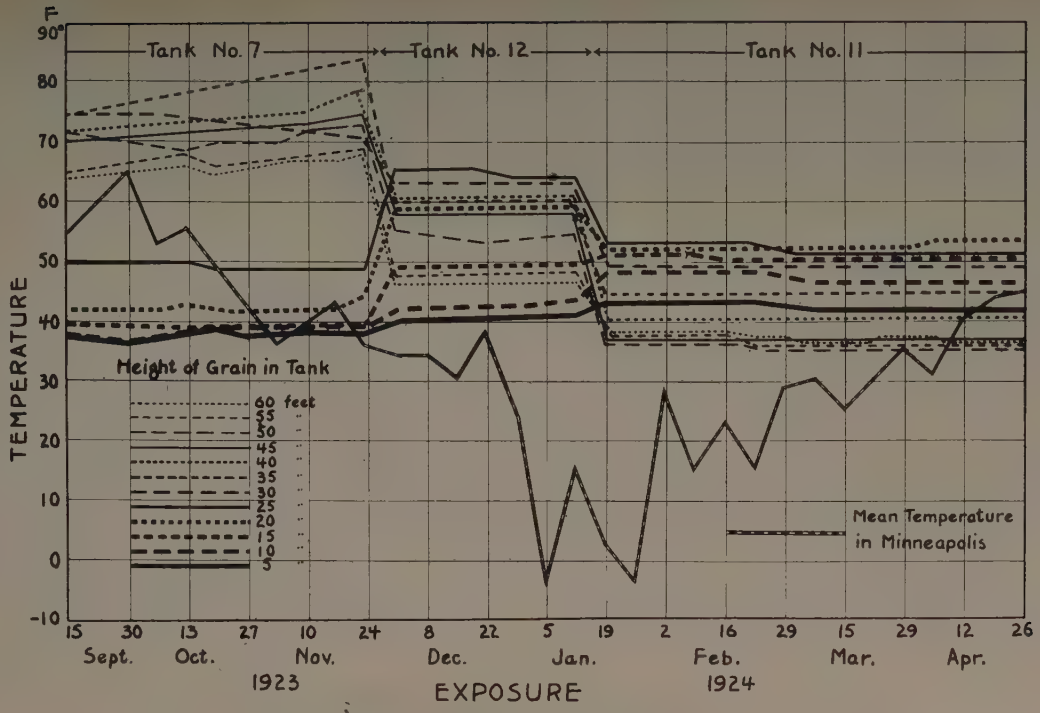


Fig. 23. Temperature of a Sixty-Foot Tank of Wheat During a Period of Seven Months

SUMMARY

A description is given of the methods and the equipment used in the experiments; and the various aspects of the subject are outlined.

In the series of abrupt exposures, where the temperatures were dropped suddenly, there was a well marked correlation between length of exposure and percentage of mortality. This is true for every temperature used.

Both species are unable to endure dormancy. *Oryza* becomes dormant at approximately 7.2° C. (45° F.) and *granarius* at 1.6° C. (35° F.); and in this condition they will perish in seventeen and thirty-eight days respectively.

During exposure to low temperatures, a continuous loss of weight occurs with each species, and this loss is regular and constant.

The gradual approach of cold weather, which "hardens" hibernating insects and enables them to survive the very low temperatures of winter, has the opposite effect upon grain weevils (and probably the whole group of non-hibernating insects) and causes death to occur more rapidly.

If the period of dormancy be broken and normal conditions be returned before death occurs, the accumulated injury can be overcome. In addition, the original vigor can be increased if the new environment be a more favorable one.

The moisture problem of grain weevils is considered.

The moisture content of grain has a marked effect upon the moisture content of the weevils. Those living in moist grain had the lowest moisture content, and a decrease of moisture in the wheat caused an outstanding increase in that of the weevils.

Weevils living in moist grain gain in weight while those in dry wheat continually lose weight.

Fluctuations in the moisture content of the wheat cause responsive changes in the weight and moisture content of the tissues of the grain weevils. Weight varies directly and moisture content varies inversely as the moisture content of the wheat. Responses continue as long as changes are made in the moisture content of the wheat.

The freezing points of grain weevils are affected by the moisture content of the grain upon which the weevils feed. Dried wheat raises and moist wheat lowers their freezing points.

Optimum, maximum, and minimum moisture content of wheat required by grain weevils are investigated. *Oryza* is more sensitive to dryness in wheat than *granarius* but neither can endure a moisture content as low as 8.2 per cent. Probably 14.0 per cent is necessary for *oryza,* while *granarius* can exist upon 12.5 per cent or slightly less. The optimum has not been definitely ascertained but is possibly around

17.5 per cent. The maximum amount is probably not more than 25 per cent, for above that amount a complication sets in by the production of carbon dioxide through increased respiration which is injurious to the weevils.

In the experiments on the attractiveness to weevils of wheat of various moisture content, it is found that moist wheat attracts and dry wheat repels.

Dry wheat causes death of the weevils, not because of the hardness of the grain covering and the difficulty of obtaining food, but through lack of moisture which brings about a breaking down of the fatty tissues of the weevils to supply the moisture required.

The moisture content of the wheat has been found to affect the ability of the weevils to resist low temperatures. Moist grain increases and dry grain decreases resistance. Correlation of moisture content of wheat and time required to cause 100 per cent mortality takes the form of a straight line.

Moisture-retaining capacity is tested by desiccation of tissues immediately after death. With cessation of life processes any individual variations are probably eliminated and a more reliable test can be made of the properties of the body structure itself to resist desiccation. *Oryza* loses its moisture content in four days while *granarius* retains some moisture for eleven days.

Weevils raise the moisture content of the wheat upon which they feed, and this results in the formation of a chain of interesting conditions each of which reacts upon the weevils themselves.

A chart is shown on which are plotted temperatures of grain in a terminal elevator in Minneapolis. This covers a period of seven months and shows that by running the grain from one tank to another during cold weather the temperature of the grain is much reduced. A suggestion is made that reducing the temperature of grain to below the minimum for the weevils might be an effective means of control.

LITERATURE CITED

Babcock, S. M.
1912. Metabolic water: its production and rôle in vital phenomena. Wis. Agr. Exp. Sta. Res. Bull. 22.

Bachmetjew, P.
1899. Der kritische Punkt und die normale Erstarrungs-Temperatur der Insecktensafte. Societas Entomologica 14: Nr. 1:1-2.

1901. Experimentelle entomologische Studien vom physikalisch-chemischen Standpunkt aus. Leipzig.

Back, E. A.
1922. Weevils in beans and peas. U. S. Dept. of Agr. Farmers' Bull. 1275, pp. 1-35.

Back, E. A. and Cotton, R. T.
1924. Effect of fumigation upon heating of grain caused by insects. Jour. Ag. Res., **28**:1103-1116.

———

1924. Relative resistance of the rice weevil (*Sitophilus oryza*) and the granary weevil (*S. granarius*) to high and low temperatures. Jour. Ag. Res., **28**:1043-1044.

Bailey, C. H. and Gurjar, A. M.
1918. Respiration of stored wheat. Jour. Ag. Res., **12**:685-713.

Bailey, C. H.
1921. Respiration of shelled corn. Univ. of Minn., Ag. Exp. Sta. Tech. Bull. 3.

Baston, G. H.
1921. Influence of weevils on temperature of wheat. Heating and spoiling of grain, pt. 1. Abstracts and References. U. S. Dept. of Agr., Bur. Markets and Crops Estimates, Grain Investigations, Project Letter 125.

Berger, B.
1907. Uber die Widerstandsfähigkeit der Tenebrio larven gegen Austrocknung. Archiv. f. d. ges. Phys. **118**:607-612.

Bodine, Joseph Hall.
1921. Factors influencing the water content and rate of metabolism of certain Orthoptera. Jour. Exp. Zool. **32**:137-169.

———

1923. Hibernation in Orthoptera. Physiological changes during hibernation. Jour. Exp. Zool. **37**:457-475.

Cole, F. J.
1906. The bionomics of grain weevils. Jour. Econ. Biol. 1, No. 2.

Cotton, R. T.
1920. Rice weevil (*S. oryza*). Jour. Ag. Res., **20**:409-422.

———

1921. Four Rhynchophora attacking corn in storage. Jour. Ag. Res., **20**: 605-614.

Davenport, C. B.
1897. The rôle of water in growth. Proc. Boston Soc. Nat. Hist., **28**:78-84.

Dendy, A.
1918. Observations on the attraction of certain grain beetles, especially weevils, by water. Reports of Grain Pests (War) Committee of the Royal Society, No. 3.

———, and Elkington, H. D.
1918. Report on vitality and rate of multiplication of certain grain insects under various conditions of temperature and moisture. Reports of Grain Pests (War) Committee of the Royal Society, No. 7.

Hall, Frank G.
1922. The vital limit of exsiccation of certain animals. Biol. Bul. **42**:31-51.

Hinds, W. E. and Turner, W. T.
1911. Calandra oryzae in Alabama; the life history of the rice weevil. Jour. Econ. Ent. **4**:230-236.

Jackson, C. M.
1925. Effects of inanition and malnutrition upon growth and structure, P. Blakiston's Son & Co., Philadelphia.

Kudo, T.
1921. Studies on the effects of thirst. Effects of thirst on weights of various organs and systems of adult albino rats. Am. Jour. Anat. **28**:

Lorenzen, A.
1887. Ueber den Einfluss der Entwasserung des Korpers auf die Entfettung. Flensburg, J. B. Meyer. 20 pp.

Nirenstein, E.
1910. Ueber Fettverdauung und Fettspeicherung bei Infusorien. Ztschr. f. allg. Physiol. **10**:137-149.

Parker, G. H. and Parshley, H. M.
1911. Reactions of earthworms to dry and moist surfaces. Jour. Exp. Zool. 11.

Payne, N. M.
1926. Freezing and survival of insects at low temperatures. Quart. Rev. Biol. **1**:270-282.

Phillips, E. F. and Demuth, G. S.
1914. The temperature of the honey bee cluster in winter. U. S. Dept. of Agr. Bul. 93, pp. 1-16.

Pratje, A.
1921. *Noctiluca miliaris* Suriray. Beitrage zur Morphologie, Physiologie und Cytologie. I Morphologie und Phys. Beobachungen an der lebenden Zelle. Arch. f. Protistenk. **42**:1-98.

Rasmussen, A. T.
1916. Theories of hibernation. Amer. Nat. **50**:609-625.

———
1923. The so-called hibernating gland. Jour. Morph. **38**:147-205.

Robinson, Wm.
1926. An electric method of determining the moisture content of living tissues. Ecology, **7**:365-370.

Sanderson, E. D. and Peairs, L. M.
1913. Relation of temperature to insect life. N. H. Agr. Exp. Sta. Tech. Bull. 7. 125 pp.

Zeleny, Anthony.
1907. Commercial temperature measurements with the thermo-electric couple. Engineer's Yearbook, Univ. of Minn., 1907, Vol. 15.

———
1909. An electrical method for the measurement of the amount of moisture in grain and other materials. The Minnesota Engineer, Vol. 17, No. 3.

University of Minnesota
Agricultural Experiment Station

Determination of Hardiness in Apple Varieties and the Relation of Some Factors to Cold Resistance

By Aubrey Claire Hildreth
Division of Horticulture

UNIVERSITY FARM, ST. PAUL

CONTENTS

Pag

Introduction 3
Acknowledgments 4
Previous work 4
Theories on the mechanism of killing by cold 4
Theories on the mechanism of cold resistance in plants 5
Means of differentiating hardy and tender plants 7
Artificial refrigeration test for hardiness 9
Methods and materials 9
Freezing determination 10
Comparison with field experience 11
Relation of factors other than low temperature to cold injury 15
Effect of length of exposure to low temperatures 15
Effect of rate of freezing and thawing 16
Effect of winter desiccation on cold injury 17
Relation of chemical composition to cold resistance 23
Materials and methods 23
Analytical procedure 24
Seasonal variations in killing point 24
Moisture 27
Carbohydrates 28
Pentosans 30
Nitrogenous materials 31
Conclusions 33
Summary 33
Literature cited 34

ILLUSTRATIONS

Page

Fig. 1. Artificial refrigeration plant used in freezing determinations 10
Fig. 2. Effect of winter desiccation on apple terminals 21
Fig. 3. Seasonal variations in killing point and variations in moisture 25
Fig. 4. Seasonal fluctuation in carbohydrates of apple twigs 30
Fig. 5. Seasonal variations in nitrogenous materials in apple twigs 32

DETERMINATION OF HARDINESS IN APPLE VARIETIES AND THE RELATION OF SOME FACTORS TO COLD RESISTANCE[1]

By Aubrey Claire Hildreth

INTRODUCTION

With the introduction of apple culture into the central northwest states and the neighboring Canadian provinces, horticulturists were faced with the serious problem of winter hardiness. In the attempt to find varieties which would endure the severe winters of this region, practically all of the standard varieties and thousands of seedlings were planted out, most of them with discouraging results. The problem has been complicated by the fact that our winters are not all equally severe. As Macoun (41), and Dorsey and Bushnell (18) have shown, test winters which seriously injure all but the hardiest varieties have usually not occurred oftener than every seven to ten years. Sometimes nearly twenty years have elapsed between them. Thus many varieties flourished for a time only to be eliminated by a test winter. This trial-and-error method, while effective in separating the hardy from the tender forms, is slow and expensive, and the need for a reliable and more rapid method of testing is patent to every pomologist.

Unfortunately, most of the varieties which have stood the test of time fall short of the standard for desirable commercial apples. Fruit breeders are making progress in overcoming this fault. Hardiness, however, is the first essential of a variety in this climate, and in order to determine the hardiness of his productions the fruit breeder must resort to long and expensive field tests. At the University of Minnesota Fruit Breeding Farm, where apple breeding is conducted on an extensive scale, this field hardiness test is becoming an increasingly difficult problem. The space, care, and record keeping necessary for the thousands of trees which will ultimately be eliminated by a test winter constitute no small item of expense. Some simple test for hardiness by which even a part of the tender individuals could be weeded out in the nursery row would greatly facilitate the work of developing hardy commercial varieties of apples.

This paper deals with a laboratory method of determining hardiness in apple varieties, together with a study of some factors which previous workers have suggested as being associated with cold resistance in plants.

[1] Also submitted to the faculty of the Graduate School of the University of Minnesota in partial fufillment of the requirements for the degree of Doctor of Philosophy, June, 1926.

ACKNOWLEDGMENTS

The writer is indebted to W. H. Alderman, Chief of the Division of Horticulture, whose interest and support made this work possible. Special acknowledgments are due Dr. R. B. Harvey, section of plant physiology, who outlined the project, suggested the method of attack, and extended full privileges of his laboratories. Thanks are extended to Dr. J. H. Beaumont for assistance in collecting data on freezing injury, to L. O. Regimbal for many suggestions on analytical procedure, and to George Steinbauer for assistance in amino-nitrogen determinations.

PREVIOUS WORK

The relation of plants to low temperatures has been given serious study for nearly two hundred years, and the literature on the subject is voluminous. Several reviews have recently appeared—Blackman (9), Chandler (12), Harvey (29), Rosa (58), Newton (51), and others—and only the more salient points in the progress of our knowledge in this field will be repeated here.

THEORIES ON THE MECHANISM OF KILLING BY COLD

Almost two centuries ago Duhamel and Buffon (20) advanced the theory that death from cold was due to rupture of the plant cells by ice formation inside them. Göppert (24) disproved this theory and attributed death to some other action of cold on cells, as no visible rupture occurred. Sachs (59) further refuted the idea of cell rupture by showing that ice normally forms in intercellular spaces and not inside the cells. From experiments and practical considerations, Sachs concluded that rapid thawing was the cause of death. Müller-Thurgau (46), however, could find no deleterious effects from rapid thawing, nor could Molisch (45), Winkler (75), or Chandler (12), with few exceptions.

Müller-Thurgau (46) proved that death was not caused primarily by cold, but resulted only on ice formation. Investigations by Molisch (45), Voigtländer (69) and Wright and Taylor (76) support this view. Müller-Thurgau (46) believed cold injury to be the result of desiccation by crystalization of the water of the cell. Matruchot and Molliard (42) and Greely (27) emphasized the similarity in effect of freezing, desiccation, and plasmolysis.

Gorke (26) believed that incident to water withdrawal for ice formation, proteins were precipitated out owing to increased salt concentration. He also noted increased acidity on freezing. Harvey (29) found increased hydrogen-ion concentration to result from freezing and believed this an additional factor in protein precipitation.

Schaffnit (63), Lidforss (38), Schander and Schaffnit (64) and Newton (50) agreed that protein precipitation is an important factor in freezing to death, tho Chandler (12) was inclined to doubt its occurrence. Maximov (43) concluded that in water withdrawal the plasma membrane suffers injury and the osmotic properties of the membrane are consequently disturbed.

Lepeschkin (36) regards cold injury as resulting from a denaturing of the protoplasm following water withdrawal to form ice. In addition to desiccation he regards the mechanical effect of protoplasmic contraction as well as pressure from ice masses as important in causing irreversible coagulation of the protoplasm.

Schander and Schaffnit (64) picture the steps in the process of freezing to death essentially as follows:

1. Ice formation in intercellular spaces.
2. Streaming of water from cells to crystalization centers.
3. Frost plasmolysis and concentration of cell sap.
4. Coagulation of all membranes and disturbance of osmotic functions.
5. Permeation of concentrated solutions of electrolytes and acids leading to coagulation of protoplasmic proteins, resulting in—
6. Death of the cell.

THEORIES ON THE MECHANISM OF COLD RESISTANCE IN PLANTS

The ability of certain plants to endure considerable cold, early attracted attention; and Greek philosophers reasoned that plants, like animals, develop heat for protection. This idea was still prevalent at the beginning of the nineteenth century, when it was overthrown by experiments of Nau (49), Shübler (65) and Göppert (24).

Müller-Thurgau (46) investigated the undercooling of plant tissues and considered this ability of some importance in cold resistance. He also demonstrated that undercooling occurred in outdoor plants on a still cold night. D'Arsonval (15) thought that undercooling occurred to a considerable degree in small cells. Voigtländer (69) showed, however, that undercooling to any extent was not general under natural conditions; and Rein (56) showed that there was no relation between cell size and resistance to low temperatures.

Contemporary theories of cold resistance generally accept as a basis Müller-Thurgau's principle that killing is a result of water withdrawal for ice formation. However, they center around two different steps in the process of freezing to death as outlined by Schander and Schaffnit (64). As Newton (51) has pointed out, there are two steps

in this scheme where protective forces come into play, one in preventing the water outgo from the cell, the other in preventing disorganization of the protoplasm.

Around these two points have developed two schools of thought on hardiness, the one attributing cold resistance to the cell's ability to limit the amount of water frozen out; the other being not so much concerned with preventing excess water loss from the cell contents as with the immunity of the protoplasm to the effects of water loss.

Adherents of the former school agree that the imbibitional forces of the cell are the chief means of preventing water loss on freezing. Müller-Thurgau (46) was perhaps the first to suggest the importance of the water-retaining power of the protoplasm in cold resistance. More recently Hooker (31), Rosa (58), Strausbaugh (68), Newton (51), Dorsey and Strausbaugh (19) and Dunn and Bakke (21) point out the importance of the imbibitional forces of cell colloids in cold endurance.

Means by which plant cells escape injury following water loss on freezing have been considered by many investigators. Sugar increase in plants on exposure to low temperatures has been observed by Müller-Thurgau (47), Lidforss (37), Fischer (23), Äpelt (2), Appleman (3), Chandler (12), Harvey (29), Rosa (58), Newton (50, 51) and others. Lidforss (38) was perhaps first to offer a plausible explanation of the significance of this transformation. He showed experimentally that sugars have the ability to protect proteins from precipitation on freezing, and concluded that in this manner the increase of sugars in plants toward winter serves as an adaptation to low temperatures. Schaffnit (63) Schander and Schaffnit (64), and Newton (51) have confirmed the results of these experiments in regard to the protective action of sugars. Blackman (9) pointed out, however, that too wide generalizations can not be made, as the sugar beet and sugar cane, altho high in sugar, develop very little cold resistance; and that sugarless bacteria, on the contrary, are very resistant. Zacharowa (77) has recently studied the freezing of young roots in detail and finds the meristematic region of the tip much more resistant to cold than the cortex or the central cylinder. The latter regions showed appreciable quantities of reducing sugars, while the hardy meristematic region was practically devoid of carbohydrates but was rich in protein materials.

Schaffnit (63) noted that proteins of hardened plants were less readily precipitated than those of unhardened plants. He concluded, therefore, that the proteins themselves change by cleavage of the larger molecules to a simpler and less labile form. Harvey (29) found indication of cleavage of proteins in hardened cabbages, the hardened plants having more than twice as much amino nitrogen as the un-

hardened. He mentions, however, that it is "not necessary nor probable that cleavage as far as to the amino acids should occur to prevent precipitation on freezing." Newton (51) failed to find any consistent differences in amino-acid content of hardy and tender wheat varieties, altho the amino nitrogen increased in all varieties with the approach of winter.

As to means of protection against increased acidity on freezing, Harvey (29) found that the more easily injured mid-rib and petiolar tissues of the cabbage were less highly buffered than the rest of the leaf. Some recent studies of Zacharowa (77) on root tips are of interest in this connection. She found that the meristematic region in seedling root tips was extremely resistant to cold while the remainder of the root was killed at a temperature slightly below freezing. Microchemical tests showed the resistant portion to be decidedly alkaline, while the other tissues were acid in reaction.

MEANS OF DIFFERENTIATING HARDY AND TENDER PLANTS

The differentiation of hardy from tender plants has received attention from many investigators and several points of difference have been reported.

Molisch (45) and Pfeffer (53) considered high osmotic pressure of importance in cold resistance. Ohlweiler (52) found direct correlation between osmotic pressure and hardiness in a number of plants. Chandler (12) found that in a given plant an increase in osmotic pressure was accompanied by an increase in cold resistance. His results were substantiated by Rosa (58), working with vegetable plants. Harris and Popenoe (28) believed that high osmotic pressure may be associated with cold resistance in the avocado.

Apelt (2) and Rein (56), however, showed that in general there is no correlation between high osmotic pressure and cold resistance in plants. Salmon and Fleming (61) found no correlation between sap density and hardiness in various cereal plants, nor could Newton (51) in studies on wheats of different degrees of hardiness.

Small size of cells was advanced by Molisch (45) as contributing to cold resistance, a view further supported by D'Arsonval (15), who estimated that in very small cells water is held under considerable capillary force and that its freezing point is in consequence materially lowered. Wiegand (74) observed that trees with small cells required lower temperature for ice formation. Rosa (58) found small cells characteristic of vegetable plants in a hardened condition. Rein (56), however, by an extensive survey of plant species, proved conclusively that size of cells bears no fundamental relation to cold resistance.

High hydrophyllic colloid content was considered by Hooker (31) and Rosa (58) as characteristic of cold resistant plants. Strausbaugh (68) and Newton (51) concurred in this view. Rosa (58) and Hooker (31) attributed the hydrophyllic properties to pentosans. Newton (51), however, found no correlation between pentosan content and hardiness in wheats; and De Long (16) was not able to substantiate Hooker's results on the relation between pentosan content and hardiness in apples. Newton (51), working on the hydrophyllic colloid theory of cold resistance, devised an ingenious method of testing wheats for hardiness. The material, after freezing, was subjected to a given pressure in a hydraulic press and the amount of juice squeezed out was measured. Imbibitional powers and cold resistance were inversely proportional to the quantity of juice obtained. On the other hand, Steinmetz (67) using the same apparatus, was unable to measure hardiness in alfalfa roots by this means. More recently, Dunn and Bakke (21) have found a high degree of correlation between hardiness in apple varieties and the hydrophyllic colloids of the cortex as measured by the ability to absorb certain dyes.

Low moisture content was found associated with hardiness by Johnson (34), Strausbaugh (68), Shutt (66), and others. Beach and Allen (8) found a similar relation in general, altho they reported that following prolonged cold the shoots of hardy varieties of apple have the higher moisture content. Their data on this point, however, show wide fluctuations and several inconsistencies. The same authors studied many morphological characters of apples and found little to differentiate them as hardy or tender. Firmness of wood seemed fairly reliable, but there were notable exceptions.

Bakke, Radspinner, and Maney (5) worked out a hardiness index factor involving the moisture content and the freezing point depression by which they were able to classify apple varieties according to hardiness.

Dorsey (17) and co-workers (18, 19) used the extent of browning, killing back, and bud injury following test winters as means of determining hardy and tender tree fruits. As this method is based on the plant's actual ability to endure winters, it is necessarily reliable, altho its practicality depends upon the frequency of test winters.

Beach and Allen (8) experimented with artificial freezing as a means of separating hardy and tender apple varieties. Altho unable to control temperatures closely, their results indicate that hardiness might be determined by this method.

In view of the fact that the mechanism of freezing to death or of cold resistance is little understood, it seemed to the writer that for practical testing some simple method was needed by which the whole

complex of factors concerned in cold resistance could be measured at once. For this purpose artificial freezing seemed most promising.

The idea of subjecting plants to low temperatures to determine their cold resistance is not new. On the contrary, the method has been employed by practically every investigator of the low temperature relations of plants. However, with the exception of the work of Beach and Allen (8), this means has not been employed, so far as the writer is aware, to test the hardiness of horticultural varieties with a view to determining their climatic adaptation. Various means of securing low temperatures have been used in experiments on plants. Early workers, as Göppert (24), simply exposed their material outside when the atmospheric temperature reached the desired point. Later, Sachs (59), Müller-Thurgau (46), Molisch (45), Winkler (75), and others used freezing mixtures of salts and snow or ice. Schaffnit (63) employed CO_2 expansion as a means of cooling. Temperatures of liquid air and other gases of low liquefaction point have been used frequently on seeds and spores. Harvey (29) and Potter (55) employed mechanical refrigeration in testing for hardiness.

ARTIFICAL REFRIGERATION TEST FOR HARDINESS

METHODS AND MATERIALS

In preliminary experiments with artificial refrigeration, conducted in 1923-24, freezing was accomplished by blowing CO_2 through an expansion coil placed inside an ordinary thermal jug. The coils were surrounded with methyl alcohol and material to be frozen was placed in wide-mouthed bottles, sealed, and immersed in the alcohol surrounding the coil. It was impossible to maintain the temperature for any length of time within several degrees of the desired point, altho in spite of this fluctuation satisfactory differences in hardiness of varieties were detectable.

A mechanical refrigerating plant was later installed, and all freezing determinations reported in this paper were made by this method. The apparatus (Fig. 1) consists essentially of an ammonia compressor and an insulated chamber cooled by the direct expansion of ammonia into coils lining the walls, and is capable of producing temperatures below —40° C. It is equipped with automatic temperature controls and also a device for varying the temperature at any desired rate. For the most part, control of ±0.6° C. of the desired temperature was possible; however, for temperatures around —40° C., fluctuations of ±1° C. usually occurred. Material to be frozen was placed loosely on wooden racks in the freezing chamber and carefully insulated from the coils. The air in the chamber was constantly stirred by an electric fan. Temperature control was verified by thermographic records.

In these studies on hardiness in apple trees, terminal growths of the last season have been used entirely. Several considerations led to the selection of this particular portion. Partial or total killing of this part is perhaps the most common form of injury to apple trees in cold climates. Macoun (40) has shown that killing back of this growth is an indication of "inherent tenderness of the variety, or of immaturity of wood." Furthermore, there is not the complicating factor of injury in previous winters that might be encountered in older parts of the tree. From the practical standpoint, terminal growths are easiest to obtain and their removal causes little damage to the tree.

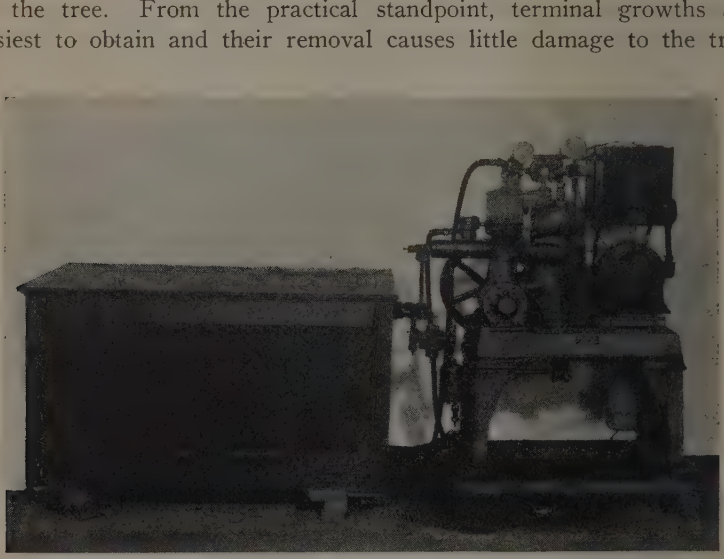


Fig. 1. Artificial Refrigeration Plant Used in Freezing Determinations

Only shoots normal in growth and more than five inches long were used, and care was taken to exclude anything in the nature of water sprouts. After collection in the field, the shoots were wrapped in waterproof paper and carried to the laboratory, where they were kept outside until used. In the growing season the leaves were stripped off at the time of collection and the shoots were packed in damp sphagnum to prevent wilting.

FREEZING DETERMINATION

From ten to fifty shoots of each variety were used in a freezing determination, and when varieties were compared at any temperature, all varieties were in the freezing chamber at the same time and were therefore subjected to the same treatment. The chamber was always cooled to the temperature of the outside air in which the twigs were kept before the samples were put in. In the usual determinations

the rate of temperature fall was 5° C. per hour. When the desired degree of cold was reached, the temperature remained constant for three hours and then rose to room temperature at the rate of 5° C. an hour. Cold injury to woody stems is not at once evident and the material after freezing must be kept for some time under suitable conditions before the extent of the injury can be determined. Various treatments were tried on the frozen twigs, such as packing in wet sawdust or sand, keeping in a cool and a warm room, placing in vessels of water, and keeping under a belljar. The method used was largely a matter of convenience, little difference being noted so long as drying out was prevented and sufficient time allowed for changes following low-temperature injury to develop. The method finally adopted was to place the samples, with cut ends down, in a deep vessel like a garbage can, add a few inches of water, place on top a loosely fitting cover, and keep at room temperature. A layer of green sphagnum on the bottom of the vessel was found helpful in preventing slimy masses of organisms that tended to collect at the base of the shoots. The partially saturated atmosphere in the can prevents excessive drying, uninjured buds open, and in a week observations may be made on amount of killing. Extent of injury was judged by growth of buds, killing back of tips, and amount and intensity of browning in pith, wood, cortex, and buds.

COMPARISON WITH FIELD EXPERIENCE

The proof of the efficacy of any artificial test for hardiness must be the conformity of its results to field experience. In Table I is shown the type of data secured from freezing determinations on shoots of different apple varieties. This material was collected on February 8, when trees were in a thoroly hardened condition. The trees from which the shoots were taken were growing at the University of Minnesota Fruit Breeding Farm, were of bearing age, and were comparable in vigor.

It will be seen that there were considerable differences in the extent of injury to the different varieties, some being killed outright while others showed practically no injury. Arranging the varieties in order of their apparent hardiness, they rank as shown in the left-hand column of Table II. In the right-hand column of this table, the varieties are grouped according to the general opinion regarding their hardiness in Minnesota. The arrangement within the groups is of no significance. This list is an adaptation from the recommendations in the Minnesota State Horticultural Society Circular for 1925. These recommendations represent the accumulated experiences of practical fruit growers and professional horticulturists and are, therefore, the most reliable information at present available as to the hardiness of these varieties in this region.

TABLE I

RESULTS OF FREEZING APPLE TWIGS COLLECTED FEBRUARY 8, 1925, AT —40° C. FOR THREE HOURS

Variety	Extent of injury*						
	Terminal bud	Lateral bud	Bark	Wood	Pith	Killing back	Remarks
Paragon	Dead	Dead	Some life	Dead	Dead	All	No growth
McIntosh	Injured	Medium	No injury	Slight	Dark	None	
Jonathan	Dead	Badly injured	Slight	Dark	do	4 in.	Practically dead
Hibernal	Trace	Slight	None	Trace	Slight	None	Buds growing
Wealthy	Medium	do	do	do	do	do	do
University	Nearly dead	Injured	do	Medium	Medium	do	do
Charlamoff	Slight	Slight	do	None	Slight	do	Good condition
Duchess (Oldenburg)	Medium	Trace	do	Trace	Trace	do	do.
Patten	Slight	Medium	do	do	Dark	do	do
Wolf River	Dead	Badly injured	do	Slight	Medium	2 in.	No growth
Delicious	do	Nearly dead	do	do	Dark	do	do
Northwestern	Nearly dead	Badly injured	do	Medium	Medium	None	
Fameuse	Badly injured	Medium	do	do	Dark	do	
Windsor Chief	Injured	Injured	do	Slight	do		Poor sample
King David	Dead	Badly injured	Some life	Dark	do	All	Probably dead
Black Ben	do	Nearly dead	do	do	do	do	do
Lansingburg	All dead	All dead	do	Dead	Dead	Dead	No growth

* The terms "dark," "medium," "slight," and "trace" refer to intensity of browning.

TABLE II

COMPARISON OF ARTIFICIAL TEST WITH FIELD EXPERIENCE

Artificial test Arranged according to hardiness	Horticultural Society rating Varieties grouped according to hardiness
Charlamoff	Duchess
Hibernal	Hibernal
Duchess (Oldenburg)	Patten
Patten	
Wealthy	Charlamoff
Windsor Chief	Wealthy
McIntosh	
Fameuse	Windsor Chief
University	
Northwestern	University
Wolf River	McIntosh
Jonathan	Jonathan
Delicious	Fameuse
King David	King David
	Delicious
Black Ben*	Northwestern
Paragon*	
Lansingburg*	Wolf River

* Not recommended by the Horticultural Society.

Some exceptions may be taken to this grouping. Charlamoff, for example, is not classed with the hardiest standard apples. Recent experiences in the trial orchards in the northern part of the state indicate that Charlamoff is fully equal in hardiness to Duchess or Hibernal, and it is almost certain that at the next revision of this list Charlamoff will be classed with the hardiest varieties. As another instance, Canadian horticulturists seem inclined to place McIntosh somewhat higher in the scale of hardiness (16), and no doubt their observations justify this arrangement. However, in the writer's opinion, this does not hold true for Minnesota. Under usual Minnesota orchard conditions, McIntosh has a tendency to make a second growth in the fall, a condition noted in certain plants in Missouri by Bradford (7). Consequently, undue winter injury may follow as a result of immaturity. This point merely illustrates the extreme complexity of the hardiness problem and indicates that the relative hardiness of varieties may vary in different regions.

From Table II it is evident that there is a close correlation between the results of this artificial freezing test and field experience. It is true that certain varieties seem somewhat out of place in the artificial test, particularly Charlamoff, which has already been discussed, and Wolf River. From the standpoint of the practical application of such a test, however, these deviations are of little significance. The important thing to note in the artificial test is that not one of the generally

recognized hardy varieties was ranked with the tender ones, and no tender ones were classed as hardy. In the three years in which these experiments have been conducted, hundreds of samples from different sources have been tested with essentially the same results. Fluctuations in the position of certain varieties occurred from time to time, but the grouping was always the same. Invariably the hardier varieties stand well toward the top and the tender ones at the bottom.

A serious objection may be made against any artificial refrigeration method of testing hardiness on the ground that it does not represent actual outdoor conditions. The question may well be raised as to whether winter injury is caused by low temperature or by some accompanying environmental factors. The close agreement of the freezing tests and field experience, and the similar nature of the injury indicate that the degree (and perhaps duration) of cold is the chief factor concerned in winter killing in this region. It is true that the winters in which greatest damage to fruit trees has occurred are not the ones having the lowest temperatures as recorded by the weather bureau. Aside from atmospheric conditions, however, there are many physiological factors within the plant which are of utmost importance in relation to cold injury. Late growth, over-bearing, disease and insect ravages all serve as modifying influences, so that the cold resistance of a tree at the coming of winter may vary from year to year. It is significant, however, that through the vicissitudes of recurring test winters certain varieties have persisted in cold regions, while others succumbed. This indicates that altho the absolute cold resistance may fluctuate, the relative order of hardiness of varieties in a given region is, in general, maintained, a matter of extreme importance in any artificial test for hardiness.

In the application of the test here proposed it can not be assumed that because a variety could withstand —40° C. in the cold chamber, it would necessarily be adapted to a region where this temperature is not exceeded. Just how far one can go in this direction is yet to be determined. The test, however, is meant to be comparative rather than absolute. In actual practice the untried variety would first be grown under similar conditions with standard varieties of known hardiness. The terminals of all would be frozen at the same time and the injury compared. In this way the hardiness could be expressed as "hardy as Wealthy," "hardier than Hibernal," "tender as Winesap," etc.

In addition to determining the cold resistance of varieties during the winter when they are in a fully hardened condition, the hardiness can be determined at any stage of activity throughout the year. When applied in the fall, the artificial freezing test furnishes a reliable guide

to the rate of hardening off, or in other words, it becomes a test for early maturity of wood. The importance of this factor in determining the adaptation of a variety to northern climates has been thoroly emphasized by Waldron (70), Macoun (39), Beach and Allen (8), and others.

RELATION OF FACTORS OTHER THAN LOW TEMPERATURE TO COLD INJURY

EFFECT OF LENGTH OF EXPOSURE TO LOW TEMPERATURES

As previously stated, the standard time of freezing in these experiments was three hours. This period was adopted because a study of the weather records for this region showed that the lowest temperatures have been of short duration, usually not more than two hours. The effect of length of exposure to low temperatures is of both practical and theoretical interest. Potter (55) logically points out that if death be due to the removal of water from the protoplasm on freezing, additional injury would not be expected so long as the temperature remained constant. However, if we adhere to the other school of thought on freezing to death and think of cold injury as due to some change in the aggregation of protoplasmic colloids, then the time factor assumes more importance, for the influence of time on changes in colloidal systems is well known.

Many writers have laid emphasis on the prolonged cold in test winters. Potter (55) has proved experimentally that length of exposure exerts a marked influence on injury in apple roots, killing being proportional to duration of freezing.

Table III shows some results of freezing apple shoots at —30° C. for three hours and for twelve hours. In every instance the longer exposure increased the injury.

TABLE III

EFFECTS OF DIFFERENT LENGTHS OF EXPOSURE TO LOW TEMPERATURES—COLLECTED JANUARY 2, 1926. FROZEN AT —30° C.

Variety	Extent of injury					
	Terminal bud	Lateral bud	Bark	Wood	Pith	Killing back
Frozen 3 hours						
Winesap	Dead	Partly dead	None	Medium	Dark	2 inches
Wealthy	Uninjured	Uninjured	do	Trace	Slight	None
Duchess (Oldenburg)	do	do	do	None	None	do
Hibernal	do	do	do	do	do	do
Frozen 12 hours						
Winesap	Dead	Dead	Dead	Dead	Dead	Entirely
Wealthy	do	Slight	None	Medium	Dark	1 inch
Duchess (Oldenburg)	do	Trace	do	do	Medium	½ inch
Hibernal	Nearly dead	do	do	Slight	do	None

EFFECT OF RATE OF FREEZING AND THAWING

Müller-Thurgau (46) showed that rapid freezing tends to produce small and irregular ice crystals while slow freezing gives larger and regular ice masses. In very rapid freezing he found ice crystals to form inside the cells, altho normally they were extracellular. Regarding the relative injury from rapid and slow freezing, Pfeffer (53) believed that there is no difference. Winkler's experiments (75), however, proved that a rapid temperature fall is much more injurious than a gradual lowering. His results have been substantiated by Chandler (12), and more recently by Carrick (11) and Potter (55).

On the effects of rapid and slow thawing, there is a divergence of opinion. Sachs (59) believed rate of thawing to be the determining factor in killing by low temperatures. Göppert (25) and Molisch (45) proved that injury results at the time of freezing. Müller-Thurgau (46) was unable to detect any deleterious effect from rapid thawing, altho later (48) he found that fruits of apple and pear were exceptions. Molisch (45) supported Müller-Thurgau's general conclusion that rate of thawing is without influence, but noted an exception in the case of leaves of *Agave americana* L. Chandler (12) found, in addition, that lettuce leaves were injured more by rapid thawing. Wiegand (74) found no relation between rate of thawing and extent of injury. Winkler (75), in experiments with deciduous and evergreen twigs, could detect no difference in injury by rapid or slow thawing, nor could Carrick (11), working with roots of several plant species. Akerman (1) found that plants subjected to temperatures slightly above the lethal point are generally more injured by rapid than by slow thawing. His method of rapid thawing was by immersion in lukewarm water. He found no differences in injury from rapid and slow thawing in air.

Some limited tests were made on apple twigs to determine the effect of rate of freezing and thawing. All terminal growths of a thrifty Wealthy apple tree were collected on December 30. They were sorted into five comparable lots of twenty shoots each for freezing. Lots 1, 2, 3, and 4 were cooled at the usual rate of 5° C. an hour. When the cold chamber reached —35° C., lot 5 was put in as quickly as possible, transferring it from a temperature of —10° C.; and freezing at —35° C. was continued for three hours. At the end of this time lot 1 was quickly immersed in rapidly flowing tap water at a temperature of 15° C. Lot 2 was plunged into a mercury bath at 30° C. for three minutes with constant stirring. In view of the high thermal conductivity of mercury this method gives perhaps the maximum rate of thawing it is possible to secure without increasing the temperature beyond the critical point. The other lots were thawed

slowly. The treatments and resultant injury are given in Table IV. The figures in the last column represent the estimated percentage of injury, total possible injury being taken as 100 per cent.

TABLE IV

EFFECT OF RATE OF FREEZING AND THAWING ON WEALTHY APPLE SHOOTS FROZEN 3 HOURS AT −35° C.

Lot No.	Rate of cooling	Rate of thawing	Per cent injury
1	5° C. an hour	Immersed in running water at +15° C.	64.4
2	do	Plunged in mercury at +30° C.	65.5
3	do	Average 2½° C. an hour	8.8
4	do	Cold chamber at 5° C. an hour	6.6
5	Suddenly from—10° to —35° C.	Cold chamber at 5° C. an hour	65.6

The rapid freezing and rapid thawing gave approximately equal amounts of injury and both are markedly more severe than when temperature changes were gradual. These results are entirely in accord with those of Akerman (1). These extremes are of only theoretical interest, as such conditions are probably never encountered in nature. The nature of the injury in both rapid freezing and rapid thawing was noticeably different from the usual type of cold injury to dormant twigs. The buds and cortical region suffered most, while wood and pith showed less injury. Normally the reverse is true, as can be seen from Tables I and III. The greater injury to buds and cortex was probably due to their being more exposed and consequently subject to more sudden temperature changes.

EFFECT OF WINTER DESICCATION ON COLD INJURY

In addition to low temperatures, the factor most commonly thought of in connection with winter injury is desiccation. Horticultural literature abounds in references to this phenomenon and the following quotations from horticultural writers show the sinister regard with which winter drying is held. Warder (71) says, "Exposure to long continued cold, with severe winds, seems to dry up the juices of the plants, in some instances, and thus effect their destruction. This, in the far north, is believed to be a frequent cause of the evil" (winter killing). Waugh (72), in speaking of winter killing of young growth, says, "It has been shown that this damage occurs largely through the drying out of the young shoots, due to the fact that, while some evaporation goes on in winter, the trees cannot take up water from the frozen soil to make good this evaporation. The young shoots become so thoroughly dried out during cold weather that the tissues are killed."

On the whole question of winter injury through desiccation, there is much circumstantial evidence but there are few data. The popularly

accepted view of the cause of such injury was expressed by Müller-Thurgau (46) as early as 1886. By experiments he proved that twigs of apple and other trees exposed outside on two cold nights lost weight. He believed that soil and stem in frozen condition were poor conductors of moisture and unable to replace water lost by evaporation from ice crystals in the frozen branches. In consequence of the water loss, the tissue died. Sachs (60) had earlier indicated the retardation of conduction with low soil temperatures by showing that in cold soil the transpiration rate of plants was materially reduced.

Investigations by Waldron (70) and Buffum (10) show greater injury when trees enter winter with dry soil. Undoubtedly root injury is here chiefly concerned, as many indications show that dry soils favor root killing. Craig (14) found root killing more prevalent in light, dry soils. Emerson (22) experimentally proved greater root injury in dry soils, which results were later substantiated by Potter (54). Emerson also showed that dry soils freeze deeper than wet ones. Potter (55), in artificial freezing experiments, proved that soil with low moisture content responds more quickly to air temperature fluctuations than damp soil. He also found that at the same temperature roots in moist soil are injured more than in dry soil, if there is any difference, thus sustaining an opinion expressed earlier by Chandler (12). Carrick (11), in freezing experiments with roots, found no consistent differences in injury at a given temperature with either moist or dry soils. Potter (55) concludes that if roots under natural conditions are injured less in moist soils, it is due to a difference in temperature. Experiments of Howard (32) under outdoor conditions are in accord with Potter's (55) findings on rate of temperature change in dry and wet soils. He failed, however, to find any differences in minimum temperatures and concludes that soil moisture exerts some protective action against cold injury. His results are open to a possible criticism, as temperature measurements were made inside a box with a perforated bottom, plunged in the ground. This might conceivably interfere with conduction of heat from the lower levels. More experiments are needed on this subject, but at present the evidence seems to favor the view expressed by Chandler (12) and Potter (55)—that temperature, rather than moisture, is the important factor in root injury.

In regard to desiccation of above-ground portions, Bailey (4) found apple twigs to lose appreciable moisture in winter in New York State. Sandsten (62), at the Wisconsin station, cut off 8-year-old apple trees and weighed them at intervals during winter to determine the water loss. Table V is adapted from his data.

TABLE V
DECREASE IN WEIGHT OF APPLE TREES IN WINTER (AFTER SANDSTEN)

	1902-03 Weight of tree				1903-04 Weight of tree	
	No. 1	No. 2	No. 3	No. 4	No. 1	No. 2
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
December 5	...	...	...	...	26.2	24.2
December 19	36.6	24.6	35.7	30.4	26.3	24.8
January 9	35.5	23.2	34.3	30.0	26.4	24.4
January 30	35.6	24.0	35.0	30.0	26.0	23.9
February 20	34.5	23.0	33.8	28.7	25.9	24.2
March 19	...	...	...	...	25.9	24.0
March 20	33.2	22.6	33.0	27.6	...	...
March 26	...	...	...	...	25.6	23.6
March 27	32.6	22.0	32.4	27.4	...	...
April 3	31.4	21.4	31.6	26.5	...	...
Loss	5.2	3.2	4.1	3.9	0.6	0.6
Per cent of weight lost	14.2	13.0	11.4	12.8	2.2	2.4

The results show marked differences in the two winters. In 1902-03, loss was near 15 per cent total weight, while in 1903-04 it was little more than 2 per cent. The latter year was described as humid. It is interesting to note that in 1902-03, when the greater loss in weight occurred, loss during two months of the presumably colder part of the year was less in every case than in approximately six weeks of warmer spring weather. No statement is made as to whether these trees showed any signs of winter injury.

Experiments of Ivanoff (33) at Petrograd, with evergreen trees severed from the roots, show that the roots exert only a small influence on the water content of leaves in winter. With deciduous twigs cut off and exposed to temperatures below freezing, he found southern species tended to lose moisture more rapidly than northern ones. He concludes, therefore, that the ability to resist winter drying is the chief factor in determining the northern range of plant species.

Some preliminary experiments on winter drying conducted in 1924-25 seem worth reporting. The object of these studies was to determine the amount of water loss from apple twigs during winter in Minnesota, its relation to temperature, and its effect in promoting winter injury. Terminal shoots were collected in winter and cut surfaces were sealed with grafting wax. They were held separately in an upright position by ordinary spring clothespins nailed on a board. This support was fastened in a fully exposed location about eight feet above the ground. The twigs were weighed outside at intervals. The data are shown in Table VI and are represented graphically in Figure 2. Both samples lost weight for the duration of the experiment, the only break occurring after a rain on February 9, when the McIntosh sample,

which had lost more, presumably by reason of longer exposure, gained weight. No comparison of varieties was intended or is possible from these data, as the two samples were put out at different times. The data for the two varieties are included merely to show that water loss is not peculiar to one variety.

TABLE VI

Loss of Weight of Twigs Cut Off and Exposed Outside During Winter

Date	McIntosh 25 terminals		Wealthy 14 terminals		Average loss per day
	Weight	Total loss	Weight	Total loss	
	gm.	gm.	gm.	gm.	gm.
December 17, 1924	201.65				
December 20, 1924	201.10	0.5			
December 23, 1924	200.6	1.0			
December 27, 1924	198.9	2.7			
January 1, 1925			194.6		
January 7, 1925	194.5	7.1	192.8	1.8	0.25
January 12, 1925	192.7	8.9	192.0	2.6	0.16
January 16, 1925	191.8	9.8	191.7	2.9	0.07
January 24, 1925	185.9	15.7	188.1	6.5	0.45
January 31, 1925	182.5	19.1	186.0	8.6	0.3
February 9, 1925	183.0	18.6	183.7	10.9	0.25
February 17, 1925	176.5	25.1	179.9	14.7	0.47
March 3, 1925	166.0	35.6	172.8	21.8	0.5
March 27, 1925			155.3	39.3	0.72
April 8, 1925			137.5	57.1	2.25
Per cent of original weight lost		17.4		29.3	
Final per cent of moisture	34.5				

The slope of the curves shows that the rate of water loss was gradual during periods of low temperature, but increased as spring opened, despite the fact that the moisture content of the twigs was being constantly diminished. These results are opposite to what would be expected if the winter desiccation rate were equal to the spring rate. In such case we should expect the logarithmic curve typical of the dehydration of colloids, which would show a high initial rate with a rapid flattening out of the curve as the last increments of moisture were more firmly held. This low evaporation rate in winter is in agreement with findings of Kosaroff (35), who showed that coniferous trees transpire from 300 to 400 times more in summer than in winter. The average daily loss for the periods between weighings is shown at the top of Figure 2. The broken line represents the average daily minimum temperatures for the same periods. Except for the rainy period, about February 9, the evaporation curve of the twigs agrees fairly closely with the temperature curve.

On March 3, part of the McIntosh sample taken for moisture determination showed a moisture content of 34.5 per cent. A similar determination made on shoots which had been left intact on the same

tree from which the original sample was taken showed a moisture content of 45.5 per cent. It is obvious that during this time considerable conduction of moisture had occurred to the twigs left on the tree.[1] Kosaroff (35) has also found that water is conducted to leafless twigs in winter; in evergreen trees, however, he found that the rate of water movement in the twigs is slowed down more, proportionately, than the rate of evaporation from the leaves.

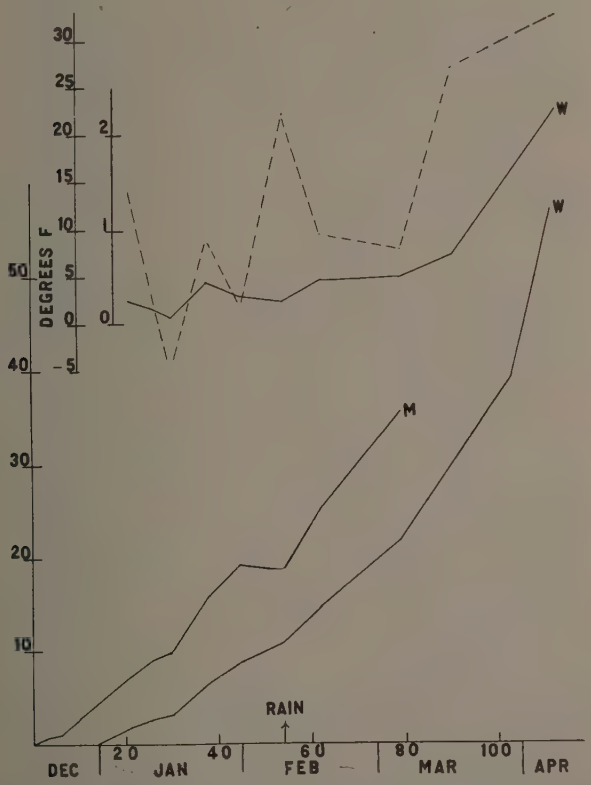


Fig. 2. Effect of Winter Desiccation on Apple Terminals

The lower curves show the total loss of weight of two varieties exposed at different times. Number of days is shown as abscissa and loss in grams as ordinates.

Above, the solid line represents the average daily rate of moisture loss of the Wealthy. The broken line shows the average daily minimum temperature for the same periods.

The remainder of the McIntosh sample used in these studies was placed in water in the greenhouse and all buds opened apparently normally. The Wealthy sample set up on January 1 lost 29.3 per cent of its original weight by April 8, altho nearly two-thirds of this

[1] The temperature of the air and possibly of trunk and branches was frequently above freezing during this period, altho the soil was frozen throughout.

loss occurred during the last month of exposure. Growth tests were not made on this material, but the entire sample was sectioned for study. It showed none of the appearances characteristic of winter injury.

In an artificial desiccation test, similar Wealthy twigs collected January 1 were waxed on the cut surfaces and placed in a sulphuric acid desiccator at a temperature of 1-3° C. for 24 days. The results were as follows:

	grams
Original weight of sample	138.90
After 24 days in desiccator	110.55
Loss	28.35
	per cent
Weight lost	20.4
Moisture content at beginning	44.8
Moisture content after desiccation	28.7

Altho these twigs had lost more than a third of their moisture, when set in water in the greenhouse the buds grew normally.

While these very limited experiments do not warrant general conclusions, certain facts are evident:

1. Cold winter weather may have relatively little evaporating effect on twigs.

2. Apple twigs are able to withstand a considerable loss of moisture in winter without injury providing later conditions are favorable for growth. Consequently, only a minimum of water conduction in cold weather would keep them well above the critical point.

3. The fact that shoots left during winter on trees in frozen soil showed considerably more moisture than severed ones, indicates that trees in winter may be able to make up, in part, moisture loss occurring from evaporation.

These remarks should not be construed to mean that "die-back" of tips in winter from deficient moisture, such as Batchelor and Reed (6) describe in the Persian walnut, in California, is at all improbable. Indeed, with a dry soil, a rate of evaporation such as was shown in these experiments in March and April would undoubtedly reduce the moisture content of the twigs below the minimum required for life. However, it seems problematic that this type of injury is in any way related to the killing-back of twigs so common in cold climates and so readily obtained by exposure to artificially produced low temperatures.

RELATION OF CHEMICAL CONSTITUTION TO COLD RESISTANCE

Studies were undertaken to determine the relation between hardiness and chemical constituents in apple twigs. Special attention was given to moisture, sugars, pentosans, and amino nitrogen, because of the significance attached to these materials by previous workers, as mentioned earlier in this paper. Comparison was made between two varieties, a hardy and a tender one, throughout the entire year. By this means it is possible to compare not only the chemical make-up of varieties of different degrees of hardiness, but of the same variety as its hardiness varies from season to season. To establish the hardiness of the varieties at different times in the year, killing tests were made in the cold chamber at each sampling for chemical analysis.

The year 1924-25, in which these experiments were made, proved excellent for hardiness studies, as the weather had many characteristics generally considered conducive to winter injury. The summer of 1924 was unusually cool with much rain, particularly in the latter part of the season. The fall was mild and there was little cold weather until shortly after the middle of December, when the coldest period of the winter was experienced. While not a test winter, there was more than the usual amount of winter injury in Minnesota.

MATERIALS AND METHODS

For these determinations Duchess (Oldenburg) and Jonathan were chosen as typifying respectively hardy and tender varieties. Five Duchess and two Jonathan trees were included. The trees, which were located at the University of Minnesota Fruit Breeding Farm, were under clean cultivation, were in good vigor, and were bearing regularly. Studies were confined to terminal shoots, which were collected and treated as previously described for artificial freezing. At each collection shoots were taken at random from all trees. The material was divided outdoors into lots for chemical analysis and for freezing tests. During freezing weather the chemical sample, wrapped in waterproof paper, was sometimes kept outside over night before preparing for analysis. At other times, however, it was prepared at once on being taken to the laboratory.

To determine the killing points of the varieties, a series of freezings was necessary, at different temperatures of 2- to 5-degree intervals. The freezing tests were carried out as previously described and after suitable time the injury was analyzed as indicated in Table I. Obviously not all possible temperatures were tried out in any test, the aim being rather to establish for each variety two narrow temperature limits, one at which it was still alive and the other at which it was

killed. The killing points recorded in Table VII represent the highest temperature at which there was no life in the sample.

ANALYTICAL PROCEDURE

For chemical analysis the entire twigs were ground in a motor-driven pencil sharpener described in an earlier publication (30), from 25 to 50 terminal growths being required for each composite sample. Mixing was accomplished by thoroly shaking in a large specimen jar fitted with a ground-glass cover. Samples were taken for moisture determination, and 50-gram samples were weighed out for analysis. This material was preserved by dropping it into boiling alcohol to which had been added one gram of calcium carbonate. After boiling for thirty minutes, the jars were sealed and stored until needed. The entire process from beginning of grinding to placing in alcohol required approximately ten minutes.

The preserved samples were further prepared for analysis by extraction with alcohol in Landsiedl extractors for eighteen hours, at which time all gave a negative Molisch test. After making up to volume, the alcoholic extract was treated with chloroform to separate out chlorophyll and lipoid material. Aliquots of the alcoholic phase were taken for sugar and amino-nitrogen determinations, the alcohol being removed in Classen flasks under reduced pressure at a temperature of 40-60° C. Determination of total and reducing sugars and amino nitrogen were made on the alcoholic extract. The residue of the alcoholic extraction was analyzed for pentosans, and for total acid hydrolizable carbohydrates. Organic nitrogen was determined from the residue of the moisture determination. Official methods of analysis of the Association of Official Agricultural Chemists were used throughout except that in sugar determinations, in which the thiosulphate method of determining reduced copper was employed, bromine water was omitted from the process. All determinations were made in duplicate except sugars, which were in quadruplicate.

Complete analytical data, together with killing points of the varieties, are shown in Tables VII and VIII. The last sample, taken July 7, 1925, was from new succulent growth. In all the graphs, data for this collection are plotted first. While not strictly accurate, this seems more logical and furnishes a more complete seasonal picture.

SEASONAL VARIATIONS IN KILLING POINT

Killing points for both varieties throughout the year are shown in Table VII and are represented graphically in Figure 3. The dotted portion of the Duchess curve in Figure 3 indicates that these killing points could not be accurately determined, owing to the difficulty of

maintaining constant temperatures below —41° C. for three hours. It is certain, however, that its killing point lay somewhere below —41° C. from Jan. 3 to March 5.

TABLE VII

KILLING POINTS AND MOISTURE CONTENT OF TWIGS OF DUCHESS AND JONATHAN APPLE TREES AT DIFFERENT SEASONS

Date	Variety	Killing point	Moisture	Condition of trees and remarks
		deg. C.	per cent	
Oct. 18, 1924	Duchess	—25	48.96	Leaves falling
	Jonathan	—15	49.84	Foliage green, no abscission
Nov. 5, 1924	Duchess	—30		Leaves mostly down
	Jonathan	—20		Leaves killed by frost
Dec. 4, 1924	Duchess	—35	48.27	No low temperature yet
	Jonathan	—30	46.46	do
Jan. 3, 1925	Duchess	Below —41	47.23	Very cold for 3 weeks
	Jonathan	—41	47.66	do
Feb. 13, 1925	Duchess	Below —41	47.66	Moderate temperature
	Jonathan	—41	45.83	do
March 5, 1925	Duchess	Below —41		Warmer, no bud activity
	Jonathan	—40		do
March 26, 1925	Duchess	—40	47.09	Buds swelling slightly
	Jonathan	—36	45.79	do
April 10, 1925	Duchess	—30	47.00	Buds opening
	Jonathan	—25	46.15	do
May 10, 1925	Duchess	— 6	51.87	Beginning to bloom
	Jonathan	— 6	52.26	do
July 7, 1925	Duchess	— 3	65.45	In active growth
	Jonathan	— 3	54.30	do
Aug. 22, 1925	Duchess		49.29	Terminal bud set
	Jonathan		52.96	Terminals still growing

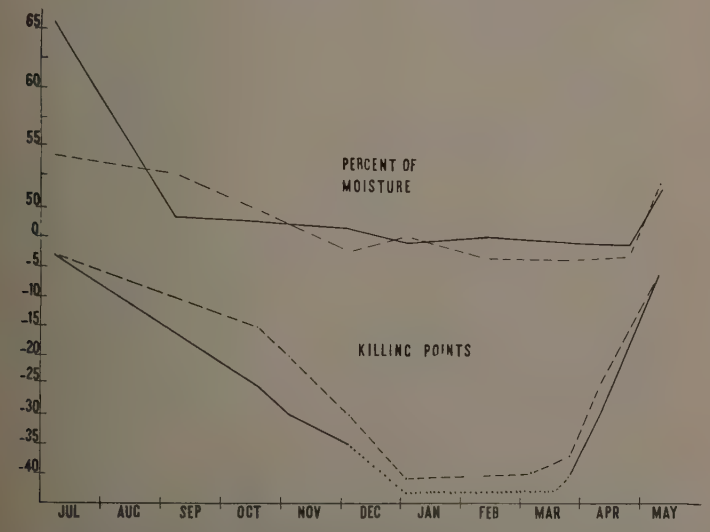


Fig. 3. Seasonal Variations in Killing Point and Variations in Moisture

The lower curves indicate the seasonal variations in killing point. The upper curves show the variation in moisture throughout the year. Solid lines represent Duchess and broken lines, Jonathan.

TABLE VIII

CHEMICAL CONSTITUENTS OF TWIGS OF HARDY AND TENDER APPLE VARIETIES AT VARIOUS TIMES OF THE YEAR

Date	Variety	Dry matter	Carbohydrates					Nitrogenous material		
			I Reducing sugars as glucose dry wt.	II Total sugars as glucose dry wt.	III Pento-sans dry wt.	IV Acid hydrolyzable alcohol insoluble as glucose	V Sum of II and IV	Total organic N. dry wt.	Amino nitrogen dry wt.	Amino N. as per cent organic nitrogen
		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Oct. 18, 1924	Duchess	51.04	1.05	1.84	15.79	30.47	31.95	0.97	0.109	11.23
	Jonathan	50.16	1.03	2.34	14.33	26.78	28.18	0.84	0.089	10.59
Dec. 4, 1924	Duchess	51.73	3.12	6.26	15.10	26.83	33.09	0.97	0.135	13.91
	Jonathan	53.54	2.89	6.00	15.69	25.66	32.66	0.82	0.130	15.85
Jan. 3, 1925	Duchess	52.77	3.25	5.85	19.10	26.77	32.62	0.98	0.142	14.48
	Jonathan	52.34	4.03	6.66	18.92	25.23	31.89	0.80	0.127	15.87
March 26, 1925	Duchess	52.91	1.67	4.23	17.51	26.54	29.77	0.98	0.128	13.06
	Jonathan	54.21	1.60	3.17	19.10	26.41	29.58	0.76	0.146	19.21
April 10, 1925	Duchess	53.00	2.26	3.04	18.82	26.16	29.20	1.10	0.158	14.36
	Jonathan	53.85	2.19	2.76	18.51	24.75	27.51	0.97	0.156	16.08
May 10, 1925	Duchess	48.13	1.46	3.07	20.64	22.39	25.46	0.71	0.195	27.47
	Jonathan	47.74	1.29	2.34	20.70	23.50	25.84	0.82	0.198	24.14
July 7, 1925	Duchess	34.55	1.77	2.61	17.77	24.15	26.76	0.99	0.228	23.03
	Jonathan	45.70	1.35	1.06	15.09	18.48	19.54	0.85	0.149	17.52

Marked variations occurred in killing points of twigs at different seasons. During summer apple shoots in active growth are no more cold resistant than many herbaceous annuals. The hardening-off process begins early in the fall and proceeds gradually until maximum hardiness is attained at about the coldest period of the year. Winkler (75) noted similar tendencies in a number of plant species, and concluded that cold itself produces an adaptation to lower temperatures.

Hardiness, once acquired, is retained until external conditions are suitable for the resumption of growth actively. The rest period of apple trees grown outside in this climate is well over by the middle of January; and if brought into the greenhouse, shoots begin to grow at once and simultaneously lose their hardiness. Consequently, it seems to be lack of conditions favorable to growth and not rest period that determines the length of the hardy period of our northern apples. Hardiness is lost much more quickly in the spring than it is acquired during the fall, and one-year-old twigs in May show little more cold resistance than the succulent summer growth. These results, in general, are in accord with previous investigations on killing points at different times of the year (12, 75). Winkler's (75) killing-point curve plotted for *Populus nigra* agrees in general with that of the apple shown in Figure 3. However, owing perhaps to the shorter winter in Germany, he found the loss of hardiness to begin much earlier than is the case with Minnesota apple trees. A study of these curves shows why a sudden drop to a low temperature in the fall or early winter may be fatal while, later, trees stand much lower temperatures without injury.

Considerable difference in lethal temperatures for the two varieties is evident. In the summer condition there is no difference in the killing points. In the fall, however, the curve for Duchess quickly drops below that of Jonathan, an expression no doubt of earlier maturity. This same relative position of killing points is maintained throughout the winter, Jonathan killing at about —40° C. while Duchess endures lower temperatures. In spring, both varieties lose hardiness at about the same rate, but the Jonathan, having less hardiness to begin with, continues to kill at a higher temperature than Duchess until active growth is resumed in May, when both varieties again have practically the same killing point.

MOISTURE

The moisture determinations made on twigs at various times throughout the year offer little possibility for distinguishing hardy and tender varieties. The moisture content was highest in summer, decreasing toward winter and rising again rapidly in spring with the resumption of growth (Fig. 3). During winter, the moisture content

of the Duchess remained practically constant, while the Jonathan showed a tendency to fluctuate more. Strausbaugh (68) noted a similar tendency toward variation in moisture of tender plum buds during winter, and Newton (51) finds similar relations in tender wheat varieties. The markedly higher moisture content of Duchess in the July sample is somewhat surprising. It is probably accounted for by the fact that the Jonathan had made almost twice as much longitudinal growth as the Duchess at this time, and consequently had a much greater amount of hard wood in proportion to the succulent tips than the Duchess. The crossing and recrossing of the moisture curves of the two varieties during winter indicates that the relation between low moisture content and hardiness reported by previous investigators (34, 66, 68) is by no means constant in the apple.

CARBOHYDRATES

The results of carbohydrate analysis are shown graphically in Figure 4. By adding the values for total sugars (curve II) to those for the acid hydrolyzable, alcohol insoluble carbohydrates (curve IV), the data plotted in curve V were obtained. These values include the carbohydrates other than the fibrous material and probably represent somewhere near the sum total of carbohydrate reserves in the twigs.

It is evident that carbohydrates, presumably of a reserve nature, are abundant in apple shoots, amounting at certain times of the year to approximately a third of the dry weight.

The curves show the highest amounts present at the sampling of December 4. Why a maximum should occur at this time is difficult to understand. It seems improbable that there is translocation of carbohydrates from other parts of the tree to the terminal shoots at this season, for these shoots only a short time before were the seat of great photosynthetic activity. The most likely explanation is that a higher point than that shown in the curves was reached considerably earlier, probably early in November, when the leaves were killed by frost, altho no analyses were made at this time.

The quantity of carbohydrate reserve falls off gradually throughout the winter and spring, owing, probably, to respiration, altho some may possibly be combined in protoplasmic transformations during the hardening-off process earlier in the winter.

The hardier Duchess had a higher carbohydrate reserve throughout the year, altho during the colder parts of the winter this difference was not great. The Duchess seems to build up its reserve earlier in the fall while the Jonathan is presumably still using its carbohydrates in late growth. (Table VII.)

Total sugars show a rapid increase from fall to winter, which is in keeping with the results of previous investigations (23, 63). Toward spring the sugars fall off much like the total reserve carbohydrates. Reducing sugars follow the same general trend as total sugars except that in spring just before the buds open there is a rapid increase, followed by a rapid decline as growth progresses.

The sugar reserves in the two varieties are strikingly similar throughout the year. There is nothing in the data to suggest that the amount of either total or reducing sugars is responsible for the difference in hardiness. In fact, the Jonathan showed slightly higher amounts of both total and reducing sugars in January, altho it would not withstand as low temperatures as the Duchess at this time. The value of sugars in protecting proteins from precipitation on freezing has been thoroly demonstrated in vitro (51, 63). However, there are many plants with very high sugar content (for example, sugar cane and sugar beet) with practically no cold resistance. It might be argued that these plants in process of growth store sugar naturally and do not develop it as a result of exposure to low temperatures. On the other hand, the potato tuber, which normally stores starch, on exposure to low temperatures will show sugar increases greatly in excess of the amount found in apple twigs (3). Apelt (2), however, was able to detect only about half a degree difference in killing point between non-hardened potato tubers and those fully hardened by exposure to low temperatures. Fischer (23) has demonstrated that in woody plants starch is transformed into sugar on exposure to cold, and that with higher temperature starch is again formed. Coville (13) has explained the increase of sugars following low temperatures as due to an increase in the permeability to enzymes, allowing the hydrolytic enzymes to come into contact with the starch. This explanation does not, however, account for the regeneration of starch at higher temperatures noted by Fischer (23).

The increase of sugars on exposure to low temperature, reported by many investigators, leaves little doubt that this phenomenon is general in starch-storing plants, and from the results of experiments in vitro (63, 51) we may conclude that sugars exert a protective action against precipitation of proteins on freezing. However, in view of the present results on the apple and the findings of Apelt (2) and Newton (51), it seems that high sugar content resulting from action of low temperatures may not necessarily result in greater cold resistance in plants. As to increased hardiness without accompanying sugar increase, Harvey (29) was able to develop cold resistance in cabbage plants without appreciable changes in carbohydrates. The lack of carbohydrates in the hardy meristematic portion of roots, as observed by

Zacharowa (77), also indicates that cold resistance may be independent of sugar content.

PENTOSANS

The data on pentosans show some interesting variations with the different seasons (Fig. 4). There is, in general, a decrease in the percentage of pentosans from summer to early winter, followed by a sharp rise to the first of January and a second rise to a maximum in May. There is probably not an actual loss of pentosans from the twig during the late summer and autumn, but the proportion is lowered, owing to the increase of other carbohydrates which occurs at this time. Conversely, in the spring the high content of pentosans may be attributed to a utilization of the more available carbohydrates, resulting in an increased proportion of pentosans, as total sugars and total reserve carbohydrates both decrease during this period. No explanation is offered for the rise in pentosan content in early winter.

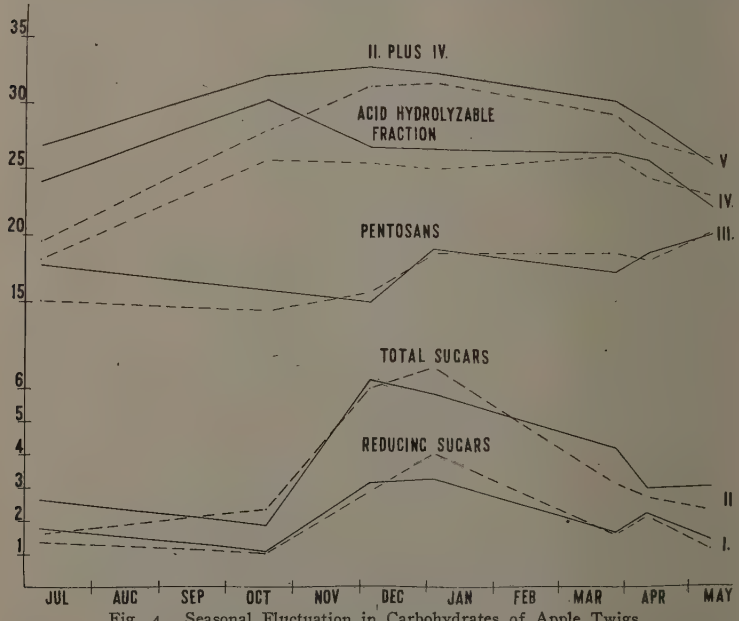


Fig. 4. Seasonal Fluctuation in Carbohydrates of Apple Twigs
Solid lines represent Duchess and broken lines, Jonathan.
Data for curve V were computed by combining the values for total sugars (Curve II) and acid hydrolyzable, alcohol insoluble carbohydrates (Curve IV).

This increase in pentosans toward winter agrees with the results of Rosa (58), Hooker (31), and Newton (51). The significance attached to pentosans in relation to hardiness by Hooker (31) and Rosa (58) has already been mentioned. De Long (16), however, failed to

substantiate Hooker's (31) results on apple varieties, and McGinty (44) has recently presented data that place Rosa's (58) results in question. Newton (51) was unable to distinguish hardy and tender wheat varieties by their pentosan content.

From the results obtained with apple shoots, there is no evidence of a relation between pentosans and cold resistance. If hardiness in the apple were dependent upon total pentosan content, we should expect apple trees to be hardiest in May and least hardy in the autumn. Between hardy and tender varieties, there is little difference in pentosan content. The Duchess variety showed somewhat higher pentosan content during the growing season, when both were equally tender. However, in the cold period of the year there is no significant difference. This is in complete agreement with determinations of De Long (16) on a number of apple varieties, as shown in the following table adapted from his data. Varieties are listed in descending order of hardiness.

Variety	Pentosans per cent
Duchess	19.09
Crimson Beauty	20.90
McIntosh	20.81
Wealthy	19.37
Fameuse	20.28
Wagener	21.49
Baldwin	19.76
Gravenstein	21.91

It is evident from these results that the hardiness of a variety of apples is not determined by the total quantity of pentosans present in the twigs.

NITROGENOUS MATERIALS

The nitrogen reserve in apple shoots is quite low and the amino-nitrogen content is extremely small. The most notable thing about the organic nitrogen content is its constancy throughout the greater part of the year, as seen in Figure 5. The greatest fluctuation occurs in spring, when there is a sudden rise about the time buds are swelling. The drop in the curves from April to May is probably accounted for in part by the fact that the nitrogen had passed outward from the twigs to the leaves, and to the growing points in the developing shoots. As these parts represented another season's growth than the one studied through the winter, they were removed at the time of collection, and are not included in the analyses.

The percentage of organic nitrogen is appreciably higher in the hardy Duchess variety than in the Jonathan. Whether this is merely a varietal peculiarity or whether it has some relation to the ability to resist low temperatures remains to be determined.

The amino nitrogen is most abundant during periods of vegetative activity. This is as might be expected, as the amino is the translocation form of organic nitrogen. There is, however, an increase in amino nitrogen during the hardening-off period in the fall and early winter. These results are in agreement with Harvey's (29) work on cabbage and with Newton's (51) analyses of wheat plants.

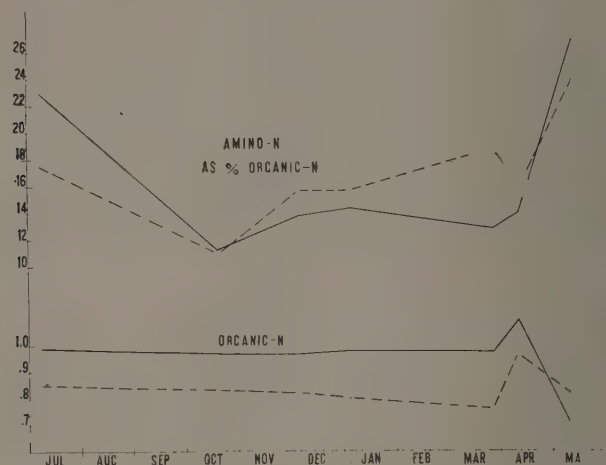


Fig. 5. Seasonal Variations in Nitrogenous Materials in Apple Twigs
The lower curves show total organic nitrogen and the upper curves show amino nitrogen expressed in per cent of total organic nitrogen. Solid lines represent Duchess and broken lines, Jonathan.

Schaffnit (63) and Harvey (29) have suggested that as a means of adaptation to lower temperatures the proteins themselves might break down to simpler and less labile forms. Harvey (29) found evidences of such transformation in the increased amino-nitrogen content of hardened cabbage plants.

If such hydrolytic processes occur in apple twigs, they can best be indicated by expressing the amino nitrogen in terms of percentage of total organic nitrogen. In Figure 4, these data are shown graphically for the two varieties of apples. There is a rather sudden increase in the proportion of amino nitrogen in both varieties from October to December. That this is the result of hydrolysis and not of synthesis, is indicated by the constancy in the amount of organic nitrogen during this period. The highest points in the curves, however, come at times when the trees are least hardy, consequently a large part of the organic nitrogen in the amino form is no assurance against cold injury. Comparing the curves of amino nitrogen with the killing curves of the two varieties, it is seen that there is no constant relationship. The

Jonathan has relatively less amino nitrogen in the fall and more in the winter and early spring, altho its killing points are uniformly higher than those of the Duchess.

CONCLUSIONS

Considering the seasonal variations in killing points together with the differences in hardiness of the two varieties used in these studies, it seems that neither moisture, sugar, pentosans, nor amino nitrogen can be considered as a primary casual factor in cold resistance. From the data on carbohydrates and total organic nitrogen, it appears that the hardy variety is better supplied with these important reserve materials than the tender one. The difference is particularly striking in the case of the nitrogen reserve. Whether this relation holds between hardy and tender varieties in general remains to be determined. If so, the whole problem of ability to resist cold may be placed definitely on a nutritional basis. Certainly there are indications that would support such an assumption. Such conditions as late growth, defoliation, over-bearing, are generally recognized as predisposing factors to winter injury. It is quite evident that these conditions would all tend to influence the amount of reserve materials accumulated.

What a survey of many varieties and species might show as to the relationship between cold resistance and abundant reserves of carbohydrates and nitrogenous materials we can only conjecture. However, the differences here noted offer an interesting hypothesis for further hardiness studies.

SUMMARY

1. Terminal growths of apple varieties of known hardiness have been exposed to artificially produced low temperatures. Classifying these varieties on the basis of the resultant injury, the order agrees closely with that of their hardiness as shown by field experience. The use of this test in determining hardiness of seedlings and varieties of unknown cold resistance seems practical.

2. Degree of cold injury is directly proportional to the duration of exposure to a given low temperature.

3. A rapid fall in temperature above the killing point is more injurious than gradual lowering.

4. When twigs frozen to $-35°$ C. were thawed by immersing in warm mercury or in running tap water, the injury was much greater than when they were thawed slowly.

5. Terminal growths of apple trees cut off and exposed for two and a half months during the coldest part of winter without moisture supply, lost 17.4 per cent of their weight but the buds opened normally when given proper conditions. Another sample lost 29.3 per

cent of its weight but showed no characteristic symptoms of winter injury. The importance of desiccation as a factor in winter killing is questioned.

6. Killing point determinations made on hardy and tender apple varieties showed great variation from season to season. Except during the growing season, the hardy variety was uniformly more resistant to cold.

7. Neither moisture content, sugars, pentosans, nor amino-nitrogen, offered a reliable basis for separating hardy and tender varieties. There was some indication that high reserves of carbohydrates and of organic nitrogen might be correlated with greater hardiness.

LITERATURE CITED

1. Akerman, A. Über die Bedeutung der Art des Auftauens für die Erhaltung gefrorener Pflanzen. Botaniska Notiser (1919): 49-64, 105-126. 1919.
2. Apelt, A. Neue Untersuchungen über den Kältetod der Kartoffel. Cohn's Bietr. z. Biol. der Pflanzen. 9:215-262. 1909.
3. Appleman, Charles O. Changes in irish potatoes during storage. Md. Agr. Exp. Sta. Bull. 167:327-334. 1912.
4. Bailey, L. H. The winter injuries. N. Y. (Cornell) Agr. Exp. Sta. Bull. 117: 385-392. 1896.
5. Bakke, A. L., Radspinner, W. A., and Maney, T. J. A new factor in the determination of hardiness of the apple. Am. Soc. Hort. Sci. Proc. 17:279-289. 1920.
6. Batchelor, L. D. and Reed, H. S. Winter injury or die-back of the walnut. Calif. Agr. Exp. Sta. Circ. 216:1-20. 1919.
7. Bradford, F. C. Observations on winter injury. I. Early and late winter injury. Mo. Agr. Exp. Sta. Res. Bull. 56:3-16. 1922.
8. Beach, S. A. and Allen, F. W. Hardiness in the apple as correlated with structure and composition. Ia. Agr. Exp. Sta. Res. Bull. 21:159-204. 1915.
9. Blackman, F. F. Vegetation and frost. New Phytol. 8:354-363. 1909.
10. Buffum, B. C. Fruit growing in Wyoming. Wyo. Agr. Exp. Sta. Bull. 34: 85-157. 1897.
11. Carrick, D. B. Resistance of the roots of some fruit species to low temperature. N. Y. (Cornell) Ag. Exp. Sta. Mem. 36:613-661. 1920.
12. Chandler, W. H. The killing of plant tissues by low temperature. Mo. Agr. Exp. Sta. Res. Bull. 8:143-309. 1913.
13. Coville, F. V. The influence of cold in stimulating the growth of plants. Nat. Acad. Sci. Proc. 6:434-435. 1920.
14. Craig, John. Observations and suggestions on the root-killing of fruit trees. Ia. Agr. Exp. Sta. Bull. 44:179-213. 1899.
15. D'Arsonval, M. La pression osmotique et son rôle de défense contra le froid dans la cellule vivante. Comp. Rend. Acad. Sci. Paris. 133:84-86. 1901.
16. De Long, W. A. Pentosan content in relation to winter hardiness in commercial varieties of the apple. Master's Thesis, McGill University. 1924.
17. Dorsey, M. J. Hardiness in top-worked varieties of the apple. Am. Soc. Hort. Sci. Proc. 15:38-45. 1919.

18. Dorsey, M. J., and Bushnell, J. W. The hardiness problem. Am. Soc. Hort. Sci. Proc. 17:210-224. 1920.
19. ———— and Strausbaugh, P. D. Plum investigations. I. Winter injury to plum during dormancy. Bot. Gaz. 76:113-143. 1923.
20. Duhamel, du Monceau, H. L. and Buffon, G. L. L. Observations des differents effects que produisent sur les végétaux les grandés gelées d'hiver et les petites gelées du printemps. Mem. Math. et Phys. Acad. Roy. Soc. Paris 233-298. 1737. Cited by Göppert (24).
21. Dunn, Stuart, and Bakke, A. L. Adsorption as a means of determining relative hardiness in the apple. Plant Physiol. 1:165-178. 1926.
22. Emerson, R. A. Experiments in orchard culture. Neb. Agr. Exp. Sta. Bull. 79:3-33. 1903.
23. Fischer, Alfred. Beitrage zur Physiologie der Holzgewächse. Jahbr. für Wissenschaft. Botanik. 22:73-160. 1891.
24. Göppert, H. R. Über die Warmeentwickelung in den Pflanzen; deren Gefrieren und die Schutzmittel gegen dasselbe. 1-273. Breslau, 1830.
25. ————. Wenn stirbt die durch Frost getötete Pflanze, sur Zeit des Gefrierens oder im Moment des Auftauens. Bot. Ztg. 29:399-402. 1871.
26. Gorke, H. Über chemische Vörgange beim Erfrieren der Pflanzen. Landw. Versuch. Stat. 65:149-160. 1907.
27. Greely, A. W. On the analogy between the effects of loss of water and lowering of temperature. Am. Jour. Phys. 6:122-128. 1901.
28. Harris, J. A., and Popenoe, W. Freezing point lowering of the leaf sap of the horticultural types of *Persea americana*. Jour. Agr. Res. 7:261-268. 1916.
29. Harvey, R. B. Hardening processes in plants and developments from frost injury. Jour. Agr. Res. 15:83-112. 1918.
30. Hildreth, A. C. and Harvey, R. B. Grinding wood samples for analysis. Bot. Gaz. 73:460-461. 1924.
31. Hooker, H. D. Pentosan content in relation to winter hardiness. Am. Soc. Hort. Sci. Proc. 17:204-207. 1920.
32. Howard, R. F. The relation of low temperatures to root injury of the apple. Neb. Agr. Exp. Sta. Bull. 199:3-32. 1924.
33. Ivanoff, L. Über die Transpiration der Holzgewächse im Winter. Ber. der deut. bot. Gesell. 42:44-49, 210-218. 1924.
34. Johnson, E. S. An index of hardiness in peach buds. Am. Jour. Bot. 6:373-379. 1919.
35. Kosaroff, P. Untersuchungen über die Wasseraufnahme der Pflanzen. Beih. z. bot. Centralbl. 11:60-80. 1901.
36. Lepeschkin, W. Kolloidchemie des Protoplasmas. 1-228. Berlin, 1924.
37. Lidforss, B. Zur Physiologie und Biologie der wintergrünen Flora. Bot. Centralbl. 68:33-44. 1896.
38. ————. Die wintergrüne Flora. Eine biologische Untersuchung. Abs. Bot. Centralbl. 110:291-293. 1909. Original, Lunds Univ. Arsskr. n. f. Bd. 2 afd. 2 Nr. 13, p. 76. 1907.
39. Macoun, W. T. The relation of winter apples to hardiness of tree. Am. Soc. Hort. Sci. Proc. 4:7-11. 1906.
40. ————. Overcoming winter injury. Am. Soc. Hort. Sci. Proc. 6:15-27. 1909.
41. ————. Winter injury in Canada. Am. Soc. Hort. Sci. Proc. 15:13-17. 1918.

42. Matruchot, L. and Molliard, M. Sur l'identitié des modifications de structure produites dans les cellules végétales par le gel, la plasmolysis et la fanaison. Comp. Rend. Acad. Sci. Paris. **132**:495-498. 1901.
43. Maximov, N. A. Chemische Schutzmittel der Pflanzen gegen Erfrieren. Ber. d. deut. Bot. Gesell. **30**:52-65; 293-305; 504-516. 1912.
44. McGinty, R. A. and Thompson, R. C. Preliminary notes on tip-burn of lettuce. Am. Soc. Hort. Sci. Proc. **22**:341-346. 1925.
45. Molisch, H. Untersuchungen über das Erfrieren der Pflanzen. 1-73. Jena, 1897.
46. Müller-Thurgau, H. Ueber das Gefrieren und Erfrieren der Pflanzen. Landw. Jahrb. **9**:133-189. 1880.
Landw. Jahrb. **15**:453-610. 1886.
47. ————. Ueber Zuckeranhaufung in Pflanzentheilen infolge neiderer Temperature. Landw. Jahrb. **11**:751-828. 1882.
48. ————. Über das Erfrieren des Obstes. Schweiz. Zeitschr. für Obst- und Weinbau. **3**:316-321. 1894.
49. Nau. H. Hat Man bis jetzt durch Versuche und Beobachtungen eine eigenthümliche Warme in den Gewächsen erwiesen? Annalen der Wetteranischen Gesell. für die ges. Naturk. **1**:27-37. 1811. (Cited by Göppert, 24).
50. Newton, Robert. A comparative study of winter wheat varieties with especial reference to winter-killing. Jour. Agr. Sci. **12**:1-19. 1922.
51. ————. The nature and practical measurement of frost resistance in winter wheat. Univ. Alberta, Col. Agr. Res. Bull. 1:5-53. 1924.
52. Ohlweiler, W. W. The relation between the density of cell saps and the freezing points of leaves. Mo. Bot. Gard. Rept. **23**:101-131. 1912.
53. Pfeffer. W. Freezing and cold rigor. Physiology of plants. Translation by A. J. Ewart. Vol. 2, pp. 232-247. Oxford 1903.
54. Potter, G. F. Root hardiness of apple seedlings. Wis. Agr. Exp. Sta. Bull. 319:37. 1920.
55. ————. Experiments on the resistance of apple roots to low temperatures. N. H. Agr. Exp. Sta. Tech. Bull. 27:2-34. 1924.
56. Rein, R. Untersuchungen über den Kältetod der Pflanzen. Ztschr. für Naturwiss. **80**:1-38. 1908.
57. Rosa, J. T., Jr. Pentosan content in relation to hardiness of vegetable plants. Am. Soc. Hort. Sci. Proc. **17**:207-210. 1920.
58. ————. Investigations on the hardening process in vegetable plants. Mo. Agr. Exp. Sta. Res. Bull. 48:3-97. 1921.
59. Sachs, J. Krystallbildungen bei dem Gefrieren und Veranderung der Zellhaute bei dem Aufthauen saftiger Pflanzentheile. Bericht. Konig. sachs. Gesell. Wiss. Leipzig. Math.—phys. Cl. **12**:1-50. 1860.
60. ————. Untersuchungen über das Erfrieren der Pflanzen. Landw. Versuchsstat. **2**:167-201. 1860.
61. Salmon, S. C. and Fleming, F. L. Relation of the density of cell sap to winter hardiness in small grains. Jour. Agr. Res. **13**:497-506. 1918.
62. Sandsten, E. P. Evaporation of water from apple trees during the winters of 1902-3 and 1903-4. Wis. Agr Exp. Sta. Ann. Rept. **21**:258-260. 1904

63. Schaffnit, E. Studien über den Einfluss neiderer Temperaturen auf die pflanzliche Zelle. Mitt. Kaiser Wilhelms Inst. Landw. Bromberg. **3**:93-144. 1910.
64. Schander, R., and Schaffnit, E. Untersuchungen über das Auswintern des Getreides. Landw. Jahrb. **52**:1-66. 1918.
65. Schübler, G. Untersuchungen über die Temperaturveranderungen der Vegetabilien und verschiedenen damit in Beziehung stehende Gegenstände. Inaugural Dissertation. Tübingen. 1829. (Cited by Göeppert, 24).
66. Shutt, F. T. On the relation of moisture content to hardiness in apple twigs. Proc. and Trans. Roy. Soc. Can. II. **9**:149-153. 1903.
67. Steinmetz, F. H. Winter hardiness in alfalfa. Minn. Agr. Exp. Sta. Tech. Bull. 38. 1926.
68. Strausbaugh, P. D. Dormancy and hardiness in the plum. Bot. Gaz. **71**:337-357. 1921.
69. Voigtländer, H. Unterkühlung und Kältetod der Pflanzen. Beit. z. Biol. d. Pflanz. **9**:359-414. 1909.
70. Waldron, C. B. Some points on fruit culture. No. Dak. Agr. Exp. Sta. Bull. 49:3-23. 1901.
71. Warder, John A. Winter killing. American Pomology, Apples. 206-208. New York. 1867.
72. Waugh, F. A. Winter killing. American Apple Orchard 14-16. New York. 1908.
73. Wiegand, K. M. Occurrence of ice in plant tissues. Plant World **9**:25-39. 1906.
74. ————. Some studies regarding the biology of buds and twigs in winter. Bot. Gaz. **41**:373-424. 1906.
75. Winkler, Albert. Über den Einfluss der Aussenbedingungen auf die Kalteresistenz ausdauernder Gewächse. Jahrb. für Wissenschaft. Bot. **52**:467-506. 1913.
76. Wright, R. C. and Taylor, G. F. Freezing injury to potatoes when undercooled. U. S. Dept. Agr. Bull. 916:1-15. 1921.
77. Zacharowa, T. M. Über den Einfluss niedriger Temperaturen auf die Pflanzen. Jahrb. f. Wissenschaft. Bot. **65**:61-87. 1925.

ARIZ. UNIV. LIB. JUL 2

TECHNICAL BULLETIN 43 SEPTEMBER 1926

University of Minnesota
Agricultural Experiment Station

A Study of the Value of the Living Vaccine in the Control of Bovine Infectious Abortion

By R. E. Lubbehusen
In Collaboration with C. P. Fitch and W. L. Boyd
Division of Veterinary Medicine



UNIVERSITY FARM, ST. PAUL

AGRICULTURAL EXPERIMENT STATION

ADMINISTRATIVE OFFICERS

W. C. Coffey, M.S., Director
Andrew Boss, Vice-Director
F. W. Peck, M.S., Director of Agricultural Extension and Farmers' Institutes
C. G. Selvig, M.A., Superintendent, Northwest Substation, Crookston
P. E. Miller, M.Agr., Superintendent, West Central Substation, Morris
O. I. Bergh B.S.Agr., Superintendent, North Central Substation, Grand Rapids
M. J. Thompson, M.S., Superintendent, Northeast Substation, Duluth
R. E. Hodgson, B.S. in Agr., Superintendent, Southeast Substation, Waseca
Raphael Zon, F.E., Director, Forest Experiment Station, Cloquet
F. E. Haralson, Assistant Superintendent, Fruit Breeding Farm, Zumbra Heights, (P.O. Excelsior)
W. P. Kirkwood, M.A., Editor, and Chief, Division of Publications
Alice McFeely, Assistant Editor of Bulletins
Harriet W. Sewall, B.A., Librarian
T. J. Horton, Photographer
R. A. Gortner, Ph.D., Chief, Division of Agricultural Biochemistry
J. D. Black, Ph.D., Chief, Division of Agricultural Economics
William Boss, Chief, Division of Agricultural Engineering
Andrew Boss, Chief, Division of Agronomy and Farm Management
W. H. Peters, M.Agr., Chief, Division of Animal Husbandry
Francis Jager, Chief, Division of Bee Culture
C. H. Eckles, M.S., D.Sc., Chief, Division of Dairy Husbandry
*R. N. Chapman, Ph.D., Chief, Division of Entomology and Economic Zoology
Henry Schmitz, Ph.D., Chief, Division of Forestry
*W. H. Alderman, B.S.A., Chief, Division of Horticulture
E. M. Freeman, Ph.D., Chief, Division of Plant Pathology and Botany
A. C. Smith, B.S., Chief, Division of Poultry Husbandry
F. J. Alway, Ph.D., Chief, Division of Soils
C. P. Fitch, M.S., D.V.M., Chief, Division of Veterinary Medicine

STAFF OF DIVISION OF VETERINARY MEDICINE

C. P. Fitch, M.S., D.V.M., Animal Pathologist and Bacteriologist
W. L. Boyd, D.V.M., Assistant Veterinarian
H. C. H. Kernkamp, D.V.M., Assistant Veterinarian
M. H. Reynolds, M.D., D.V.M., Veterinarian
Earl A. Hewitt, B.S., D.V.M., Assistant Veterinarian
R. E. Lubbehusen, B.S., D.V.M., Assistant Pathologist

* On leave, 1926-27.

Reprinted from The Cornell Veterinarian, July, 1926

A STUDY OF THE VALUE OF THE LIVING VACCINE IN THE CONTROL OF BOVINE INFECTIOUS ABORTION *

By R. E. LUBBEHUSEN,
collaborating with C. P. FITCH *and* W. L. BOYD
Division of Veterinary Medicine, University Farm

Since the discovery by Bang of *Bacterium abortus* as the definite cause of bovine infectious abortion this organism and the disease it produces has commanded the attention of investigators and others interested in the cattle industry. Early recognition of the serious economic losses incurred by this disease has led to extensive studies directed toward effective control measures. The previous success of vaccine therapy in the control of certain other infectious diseases stimulated inquiry relative to the control of infectious abortion by the use of biological agents. Although the reported studies represent extensive work by prominent investigators the results are so variable as to leave much doubt as to the relative merits of any particular agent beyond the general statement that no reliable prophylactic or therapeutic agent has yet been found. Brief reference to certain reported investigations carried out on the same general plan as the work here reported is made for purposes of direct comparison.

Hart and Traum[1] in their most recent report on the relation of the subcutaneous administration of the living *Bacterium abortus* vaccine to the immunity and carrier problem of bovine infectious abortion, give the results of their observation on 56 females through two pregnancies. In group No. I, consisting of 20 animals which were vaccinated and later artificially infected, 17 animals became pregnant during both years with no losses due to abortion. In control group No. II (a), comprising 10 animals which were not vaccinated but artificially infected, six of 10 pregnancies terminated in abortions the first year. During the second year, 9 pregnancies resulted in as many normal calves. Control group (b), consisting of 5 non-vaccinated and non-infected females, 10 pregnancies over a two-year period terminated in normal calvings. In group No. III, comprising 10 vaccinated females not arti-

* Published with the approval of the Director as Paper No. 606 of the Journal Series of the Minnesota Agricultural Experiment Station.

ficially infected, 4 pregnancies the first year and 8 pregnancies the second year resulted in as many normal calvings. As a result of these observations the authors conclude in part: "The value of the living cultures of *Bacterium abortus* in preventing abortion in vaccinated animals when subjected to identical infection that produced abortion in the control animals was demonstrated."

Buck and Creech[2] report one abortion to 22 pregnancies of 11 animals which had received a subcutaneous injection of 20 cc. of living *Bact. abortus* Bang, and artificial infection after becoming pregnant. In the control group, consisting of 8 non-vaccinated and artificially infected animals, 8 pregnancies ended in 7 abortions. The authors further report the results obtained by the use of the living vaccine in a large dairy herd of 1141 animals of which 772 were vaccinated while the remainder were left as controls. Six hundred and seventeen pregnancies in the vaccinated group terminated in 81 (13.1 per cent) abortions, while 294 pregnancies in the control group terminated in 52 (17.7 per cent) abortions. The second gestation period with a lesser number of animals terminated in 10.3 per cent abortions for the vaccinated and 14.1 per cent abortions for the control group. These figures are only of relative value in that they were based largely upon clinical observations and not carefully controlled bacteriological examinations. In discussing the results obtained under experimental conditions, the authors state, "Considerable encouragement was derived from the results obtained with living abortion organisms."

Smith and Little[3] after extensive studies on vaccinal immunity toward infectious abortion summarize and conclude in part:

"1. In one experiment comprising 134 controls and 53 vaccinated heifers, the abortion rate following vaccination with living cultures was 16.7 and 11 per cent respectively for the first and second pregnancies as compared with 25.1 and 19.2 per cent for the control groups.

"In a second experiment comprising 35 heifers treated with heated cultures and 10 with living cultures, the combined abortion rate for the first pregnancy was 14.7 per cent as compared with 41.6 per cent for 38 controls. The rate for the 10 treated with living cultures was zero. The above

estimates do not include those cases in which full term pregnancies were associated with infected or diseased placentas.

"2. Vaccination with living cultures should be applied only in herds in which abortion in the first pregnancy is frequent and in which cows freshly introduced abort the first or second calf."

"3. Vaccination with small doses of living bacilli (one agar slant or less) practiced two or three months before conception is not a dangerous process."

The experimental work recorded in this paper was projected during the summer of 1922. At that time the results obtained in our study of the immunity induced by the living vaccine under experimental conditions, and artificial infection[4] suggested a detailed observation on the efficiency of this agent under farm conditions and natural infection. The results obtained in both experiments and the conclusions drawn therefrom while not identical are very similar. These results indicate that the exposure to infection under natural conditions was as rigorous as that induced artificially in the experimental herd.

The principal object in undertaking this work was to study the effectiveness of the living vaccine in producing an immunity toward *Bact. abortus* Bang infection. Certain other problems closely associated and of such vast importance as to influence the efficacy and desirability of its use have also been studied. We refer especially to the carrier problem of those animals which are vaccinated; the length of time they harbor infection and the danger of their acting as disseminators of the disease to non-infected animals. Aside from the immunizing value of the living vaccine and the danger of the carrier problem arising from its use, one must also consider its effect upon the reproductive organs and subsequent breeding efficiency if we are to judge of its practical application and merits.

EXPERIMENTAL PROCEDURE

The Herd.—The data here presented are our observations on a total of 60 animals comprising members of a pure bred dairy herd which had suffered losses from abortions for a number of years. Such clinical abortions according to available herd records had ranged from 11.3 to 21 per cent during

the years of 1917 to 1921 inclusive. Many of these abortions were due to *Bact. abortus* Bang infection. This is true because in 1918 when the first sera tests of the herd were made, 72 per cent of the animals gave suspicious or positive reactions and 27.7 per cent gave negative evidence of *Bact. abortus* Bang infection. In 1919, 58.7 per cent of the herd gave a positive reaction while 40.2 per cent were negative. This increase of negative animals over the previous year is explained by the presence of a larger number of heifer calves. The percentage of infection remained approximately the same during these years and the herd may be classified as badly infected, and one in which the effectiveness of an immunizing agent might be judged.

Methods.—At the beginning of the experiment the herd was divided into two groups, equal as to number and per cent showing positive serologic evidence of infection. Due to our endeavor to conduct this work on a practical basis we did not interfere with the normal movement of animals into and out of the herd. This naturally led to the addition of animals to either vaccinated or control groups as occasion required in order that the equality in number be maintained. This addition to the groups also applied to those heifers raised in the herd upon attaining breeding age. All animals were maintained under the same conditions with no attempt at isolation except shortly before and following parturition, a practice which is normally followed in any well managed herd. All of the experimental animals received the same care at parturition and every effort was made to correct the pathologic processes incident thereto by frequent examinations and treatments. Since the herd comprised four of the dairy breeds, a like number of bulls were used throughout the experiment. Frequent serologic tests were run on these animals but always with negative results. Both reacting and non-reacting females were served by the same sire. No special precautionary measures such as douching of the sheath or disinfectant treatment of the buttocks of the female, were practiced. No female was released from quarantine or bred until the genitalia had returned to normal and discharges ceased. All sires used throughout the experiment were potent, with difficult conception and sterility attributable to pathologic changes in the female reproductive organs. In no instance was any animal subjected to artificial infection, beyond that induced by the

use of the living vaccine. The efficiency of the live organisms in producing an immunity toward abortus infection in this report must therefore be judged on the basis of natural herd infection and the extent of this disease in the control group.

Vaccination.—In the preparation of the vaccine considerable care was exercised to select strains of known pathogenicity freshly isolated from a variety of sources. As a rule, four strains isolated from fetal stomach contents, placental material, milk and colostrum were used. In several instances a strain isolated from a testicular infection were also included. The cultures were grown on serum agar media for a period of five days under 10 per cent CO^2 tension. After examining all transfers for purity, the growth was washed with normal saline solution and diluted to a density of tube No. 2 of the MacFarland Nephelometer. To insure the use of viable organisms, the vaccine was always injected within three hours following its preparation. This three-hour period was purely arbitrary and was simply followed in order that the method used and loss in viability may be comparable throughout the experiment. In order to check the possible importance of the quantity of vaccine used, the dosage varied in the amounts of 60, 45, and 20 cc. per individual. All injections were made subcutaneously in the prescapular region. In those individuals comprising the initial group where 60 cc. of the vaccine was injected at a single point, considerable trouble was experienced with swelling and abscess formation. This difficulty was subsequently very largely overcome by multiple injections over a larger area. Beyond a temporary rise in temperature, and in a few animals a short period of malaise, no general disturbance was evident after vaccination. All heifers were vaccinated sixty days prior to being bred. In those instances where cows were added to the vaccinated group, or where an animal was revaccinated, such individuals were vaccinated just as soon as involution had taken place. In no instance was an animal revaccinated unless the serologic tests indicated a decrease in the agglutinins or complement-fixing antibodies.

METHODS OF STUDY

It will be found that the recorded data represents observations resulting from clinical, serological and bacteriological

study of individuals belonging to the vaccinated and control group. The clinical observations comprise such points as: (a), Number of services per pregnancy; (b), Duration of Pregnancy; (c), Number of healthy calves; (d), Number of abortions; (e), Pathologic and physiologic changes at the time of parturition; (f), The breeding efficiency.

The serological observations included the sera tests of all animals in the herd, including heifers of 6 months and bulls used in service. The agglutination and complement-fixation tests were used at least once every 6 months and sometimes with greater frequency as our observations in individual cases seemed to demand. The serum dilutions for the agglutination tests were 1 : 25, 1 : 50, 1 : 100, 1 : 200, 1 : 500, 1 : 1000. During the forepart of the experiment the serum dilutions employed in the complement-fixation test were 0.1, 0.5, and 0.025 cc., which were later (May, 1925) changed to 0.1, 0.04, 0.02, and 0.005.

Bacteriologic Examinations

In view of the fact that abortions may be the result of other causes than infection with *Bact. abortus* Bang it is a matter of utmost importance that a thorough bacteriologic study be made of all fetal material if we are to form an accurate opinion of the efficiency of an immunizing agent. The possible dangers resulting from the use of the living organism as an immunizing agent, in creating carriers of the disease and the presence of the organism in the animal body can only be determined by a bacteriological examination of those excretions and secretions in which *Bact. abortus* Bang is eliminated. The same bacteriologic examinations were made on members of each group regardless of the sereologic evidence of the presence or absence of *Bact. abortus* Bang infection. While a bacteriologic study of the placental membranes, colostrum, and milk of non-reacting individuals may seem superfluous, the results obtained have been such as to contribute valuable data to the carrier problem and control of abortion by the use of the serologic tests.

Bacteriologic examination of fetuses consisted of cultures of the lungs, liver, spleen, kidneys, and contents of the abomasum. In each instance, two guinea pigs were injected with 2.5 cc. of stomach contents obtained from the abomasum.

Where abortions occurred in early pregnancy or where the abortion took place while the animal was at pasture and the fetus was not recovered, the vaginal discharge was examined by culture and guinea pig inoculation. Immediately upon removal or expulsion of the placental tissues the chorion was examined and numerous tufts, especially those showing gross evidence of pathological changes were removed. The material thus obtained was cultured, smear preparations were stained for microscopic examination, while other portions were placed in a sterile mortar and thoroughly triturated with the addition of physiologic saline. Approximately 0.5 to 1.5 cc. of this saline suspension was injected intraperitoneally into each of two guinea pigs.

In order to study the presence of *Bact. abortus* Bang infection in the udder and its elimination therefrom in the vaccinated and control groups, milk samples were obtained from each individual about three times per lactation period. Occasional drying off, sale of the animal, mastitis, and official test work interfered with rigid carrying out of this program. The technique employed in the milk examinations was that described by Fitch and Lubbehusen.[5]

All guinea pigs used for inoculation purposes throughout this experiment were those whose sera had given negative serologic evidence of infection with *Bact. abortus* Bang. The practice is a simple one and eliminates erroneous conclusions due to natural infection.

PRESENTATION OF DATA

A concise and easily understandable presentation of the data at hand is somewhat difficult due to the detailed work involved in the study of the problem and the plan of the experiment which did not interfere with the normal movement of animals into and out of the herd. It will be noted (Charts I and II) that the number of pregnancies per individual vary from one to four, due to the addition of animals to both groups at intervals when replacements were required. The procedure likewise necessitated the vaccination of individuals at irregular intervals as they became available for use. To assist in presenting the collected data in a form which will aid in a ready interpretation of the results, and claim the interest of the clinician as well as the bacteriologist and immunologist

we have abandoned an extended protocol treatment, and have resorted entirely to the use of charts. We have further endeavored to group the data into three divisions, namely: (a) Clinical observations; (b) Bacteriologic findings; (c) Serologic reactions. Each embraces a field of interest and it is only by correlating the data thus obtained that final conclusions can be drawn.

The clinical observations (Charts I and II) present: (a), the quantity of vaccine used and dates of vaccination; (b), Number of pregnancies; (c), Number of services per pregnancy; (d), Dates of normal calvings; (e), Dates of abortion; (f), Length of gestation period; (g), Retention or expulsion of fetal membranes; (h), Present condition, with general remarks.

The Data included in the bacteriologic findings (Charts III and IV) comprise: (a), Dates of normal calvings; (b), Dates of abortions; (c), Results of the bacteriologic examination of fetuses, placenta, and milk. In the latter is included the number and dates of examination.

The results of the serologic tests (agglutination and complement-fixation) on the vaccinated and control groups, together with dates and reaction of the dam, where possible, are all included on Chart V.

SUMMARY OF THE CLINICAL DATA

Vaccinated Group

There are presented in this group a total of 51 pregnancies of which 42 are terminated at the present writing. Of this number 34 cows (or 81 per cent) calved normally, while 8 (or 19 per cent) aborted. With the exception of animals 533 and 534 that aborted on the 112th and 156th day respectively, abortions occurred between the 180th and 244th day of gestation with an average of 198 days. There were 131 services required for 51 pregnancies or an average of 2.55 per pregnancy. The average number of pregnancies for the 27 animals under consideration was 1.88. The fetal membranes were expelled following 29 (or 69.5 per cent) and retained following 13 (or 30.9 per cent) of the pregnancies. Of those animals that calved normally, 17.64 per cent suffered from

retention of the fetal membranes, while 87.5 per cent of those that aborted were affected in like manner.

Control Group

In this group there were a total of 79 pregnancies, 66 of which are terminated at the present time. Of the 66 terminated pregnancies, 47 cows (or 71.2 per cent) calved normally while 19 (or 28.7 per cent) aborted. In two instances, animals Numbers 8 and 138, abortions occurred at approximately two months, after each had been declared pregnant by absence of œstrum and physical examination. The remaining 17 abortions occurred between the 145th and 255th day of gestation with an average of 209 days. Seventy-six pregnancies (3 animals were pregnant when purchased) required a total of 195 services or an average of 2.56 per pregnancy. The average number of pregnancies per animal was 2.39. The fetal membranes were expelled following 44 (or 66.6 per cent) of the pregnancies. Of the animals that calved normally 17 per cent suffered from retention of the fetal membranes while 73.7 per cent of those which aborted were similarly affected. It is of further interest to note that only 8.5 per cent of the animals that calved normally and suffered from retention of the fetal membranes failed to show serologic evidence of *Bact. abortus* Bang infection.

DISCUSSION OF THE CLINICAL DATA

The general use of many immunizing agents has and will largely depend upon clinical manifestations of efficiency, with the result that the proper interpretation of clinical facts gathered in work of this kind is not only necessary, but is many times of far-reaching importance. The degree in which the clinical data and conclusions drawn therefrom can be supported by a bacteriologic study, is variable. It may be said that final conclusions can only be drawn by a correlation of the clinical and bacteriologic findings. Although it was our intention at the onset of the experiment to collect data on an equal number of pregnancies from each group, it will be noted that the pregnancies presented by the vaccinated group are considerably less than those of the controls. It will be noted that this inequality is not due to a lower breeding efficiency

but to the disposal of animals by sale, reaction to the tuberculin test, and death. In order, therefore, that the results obtained in the two groups might be directly comparable, the data must be considered on a percentage basis. The vaccinated group presents 8 or 19 per cent abortions out of 42 terminated pregnancies. Cow 140 is the only animal that aborted twice. The control group represents 66 terminated pregnancies, 19 (or 28.7 per cent) of which resulted in abortions. Four of the animals; namely, 134, 138, 374, and 537, aborted twice. These figures not only show a larger per cent of abortion in the control group but the percentage of animals involved is greater. Of the five animals that aborted twice, 4 (or 80 per cent) belong to the control group.

The retention of the fetal membranes is always to be viewed as a manifestation of placentitis, often of bacterial origin. While a number of bacteria have the power of invading the placental tissues, this condition is so commonly associated with *Bact. abortus* Bang as to be viewed by many as symptomatic of infection with this organism. In the vaccinated group the fetal membranes were retained in 30.9 per cent, and the control group in 33.3 per cent of the cases. The close association of retained placenta and abortion may be gathered from the fact that 87.5 per cent of the vaccinated and 73.7 per cent of the control animals that aborted retained their placentas. This figure would have been still higher were we to eliminate from our calculations those abortions occurring before the third month of gestation. That retention of the fetal membranes following apparently normal calvings is fairly constant may be concluded from the fact that 17.6 per cent of the normal calvings in the vaccinated group and 17 per cent in the control group were so affected. Just what percentage of these retentions are due to infections with *Bact. abortus* Bang will be discussed in connection with elimination of the organism. That retention of the fetal membranes may and does occur without infection with the Bang organism is evident in that 8.5 per cent of the animals that calved normally and retained the fetal membranes failed to show serologic evidence of *Bact. abortus* Bang infection. According to our observations, the assumption that retention of the fetal membranes is indicative of infection with *Bact. abortus* Bang would probably be correct in approximately 90 per cent of the cases.

A fair estimate of the breeding efficiency of the vaccinated and control group may be obtained by comparing the average number of services per pregnancy and average number of pregnancies per animal. Inasmuch as the same proven sires were used upon members of both groups, and all animals received proper treatment as occasion required, failure to conceive was due to temporary or permanent pathologic changes in the female genitalia.

The average number of services per pregnancy in the vaccinated group was 2.55 as compared with 2.56 for the controls. Despite the fact that both groups appeared to conceive with equal readiness, the average number of pregnancies was 1.88 and 2.39 for the vaccinated and control groups respectively. This seeming discrepancy may be explained by the fact that a number of the animals of the vaccinated group were disposed of when "open" following the termination of only one pregnancy.

Since animals in both groups seem to balance in their ability to conceive, and both suffer in approximately the same percentage from temporary pathologic involvement of the genitalia, the efficiency of the living vaccine from a clinical viewpoint must be judged by the decrease in the number of abortions and the probably increase of permanent pathologic changes in the genitalia attributable to its use. A review of the clinical data of the vaccinated group shows that animals 363, 523, and 355 were sold as sterile. After calving twins on August 18, 1925, cow 363 developed metritis, which became chronic. The development of adhesions involving tubes and ovaries together with a number of small abscesses rendered the animal sterile. Cow 355 calved normally on September 6, 1924. The fetal membranes were expelled one hour after calving and involution took place in a normal manner. She was bred on September 29, October 23, and November 12, 1924. A persistent *corpus luteum* was removed from the left ovary on January 12, 1925. She was bred four days later. On March 13, 1925, a *corpus luteum* was removed from the right ovary, Estrum appeared two weeks later, but continued breeding failed to result in conception. After four services she was again examined and found to be affected with salpingitis and cystic changes of the left oviduct and ovary. Removal of the affected ovary and tube was performed. Recovery was uneventful and the cow was again rebred a

number of times without success. She was then sold for slaughter. Cow 523 was a large coarse heifer with masculine tendencies and was temporarily sterile as a heifer. After numerous services she conceived and on January 2, 1923, she calved normally. The fetal membranes were promptly expelled and involution progressed normally. Later, cystic changes occurred in the right ovary. The cysts were ruptured on Jaunary 15th, and again on the 26th of January. An examination of the reproductive organs on February 21, 1923, showed all organs to be apparently normal. This cow was then bred seven times without successful conception. On account of reduced fertility together with the gradual increase in masculine appearance she was sold for slaughter. In the control group, only one animal, 142, was sold as sterile. Sterility in this instance resulted from cystic degeneration of the ovaries. Although this animal was a strong positive reactor, and suffered from abortion on the 220th day of gestation, bacteriological examination failed to show the presence of *Bact. abortus* Bang in either the fetus or placental membranes.

We desire to call attention to animal 101 as being temporarily and possibly permanently sterile, although she is being retained in the herd and is now undergoing treatment with the hope she will again calve successfully. This cow is an aged Jersey which has produced twelve strong and vigorous calves which stamps her as a wonderful breeder. This record is especially significant on account of the fact that she has for a greater portion of her life been continuously exposed to abortion infection. At her last calving date, December 8, 1924, she produced a strong, vigorous calf but suffered partial retention of the fetal membranes. The existing placentitis developed into an extreme metritis involving mainly the left cornu, oviduct, and ovary. Recovery was rather slow and resulted in fairly extensive adhesions involving the left oviduct and ovary. This cow reacted on numerous occasions to the serologic tests, but was never strongly positive and on one occasion gave a negative reaction. The presence of *Bact. abortus* in the excretions or secretions of this cow has never been demonstrated.

In considering the cases of sterility in the vaccinted group, and their probable relationship to the use of the living vaccine, it is of interest to note that the organism was not

recovered in a single instance, either following normal calving or in the discharges incident to a metritis.

SUMMARY OF BACTERIOLOGIC DATA

Vaccinated Group

A study of Charts III and IV shows that the bacteriologic data comprises examinations of fetuses, placentas, and frequently of milk samples for the presence of *Bact, abortus* Bang infection. As has been stated, this study has embraced both the direct culture method and guinea pig inoculation. In order that the data may be condensed and the basis for our interpretation of the bacteriological findings more readily understood the results are presented in the following table:

TABLE I

Summary of the Bacteriologic Data of the Abortions in the Vaccinated Group (Eight Abortions)

Animal	Fetus	Placenta	Discharge	Milk	Reaction	Remarks
364	—	—	..	—	+ + + — — —	Not due to *Bact. abortus* Bang.
140	—	+	..	..	+ + + + + +	Due to *Bact. abortus* Bang.
520	+	+	..	..	+ + + + + +	Due to *Bact. abortus* Bang.
531	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
534	..	+	..	—	+ + + + + +	Due to *Bact. abortus* Bang.
140	..	+	..	..	+ + + + + +	Due to *Bact. abortus* Bang.
361	..	..	..	+		Questionable. Probabaly due to *Bact. abortus* Bang.
533	..	..	—	..	+ + + + + +	Questionable. Very early abortion.

Of the 4 fetuses examined 2 were positive while 2 were negative for *Bact. abortus* Bang infection.

Of the 6 placentas examined 5 were positive while 1 was negative for *Bact. abortus* infection.

Two of the four animals examined eliminated the organism in the colostrum or during the lactation following abortion.

Referring to the bacteriologic study of the placenta of normal calvings, we find that two of the 27 examined, or 7.4 per cent, showed the presence of *Bact. abortus* Bang. Considering the elimination of the organism from the entire vacci-

nated group, we find that 7 or 26 per cent of the animals eliminated *Bact. abortus* Bang in the milk while in 6 or 22.2 per cent the organism was found in the placenta or uterine discharges, with a total of 30 per cent of the animals acting as spreaders of infection by elimination of the organism from one or both channels.

Control Group

The outline of our bacteriologic findings and interpretation of the results is as follows:

TABLE II

Summary of the Bacteriologic Data of the Abortions in the Control Group (Nineteen Abortions)

Animal	Fetus	Placenta	Discharge	Milk	Reaction	Remarks
134	+	+	..	—	+ + + + + +	Due to *Bact. abortus* Bang.
134	+	..	+	—	+ + + + + +	Due to *Bact. abortus* Bang.
138	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
153	+	+	..	..	+ + + + + +	Due to *Bact. abortus* Bang.
360	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
374	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
375	+	+	..	..	+ + + + + +	Due to *Bact. abortus* Bang.
521	+	+	..	—	+ + + + — —	Due to *Bact. abortus* Bang.
528	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
537	+	+	..	—	+ + + + + +	Due to *Bact. abortus* Bang.
537	+	+	..	+	+ + + + + +	Due to *Bact. abortus* Bang.
142	—	—	..	+	+ + + + + +	Not due to *Bact. abortus* Bang.
143	—	—	—	..	— — — — — —	Not due to *Bact. abortus* Bang.
152	—	—	..	—	— — — — — —	Not due to *Bact. abortus* Bang.
368	—	—	..	—	— — — — — —	Not due to *Bact. abortus* Bang.
377	—	—	..	—	— — — — — —	Not due to *Bact. abortus* Bang.
8	..	..	..	—	+ + + + + +	Questionable. Very early abortion.
138	..	..	..	+	+ + + + + +	Probably due to *Bact. abortus* Bang.
374	..	—	..	+	+ + + + + +	Probably due to *Bact. abortus* Bang.

Of the 16 fetuses examined 11 were positive and 5 were negative for *Bact. abortus* infection.

Of the 17 placentas examined 11 were positive and 6 were negative for *Bact. abortus* infection.

Eight of the animals eliminated *Bact. abortus* Bang in the colostrum or during the lactation following abortion.

In this group, the bacteriologic examinations of the placentas of normal calvings demonstrated the presence of the organism in 4 or 12.1 per cent of a total of 33 examined. In this group 8, or 24.2 per cent, of the animals eliminated *Bact. abortus* Bang in the milk while the organism was recovered in the placentas of 12, or 36.3 per cent, of the animals. Forty-two and four-tenths per cent of all members of the group eliminated *Bact. abortus* Bang and thus acted as spreaders of infection.

DISCUSSION OF THE BACTERIOLOGIC DATA

The importance of the bacteriologic data in a study of this kind and the influence of such findings upon the final interpretation of the results obtained is of two-fold importance: First, in determining what per cent of abortions are actually due to the Bang organism; and, second, regardless of the serologic reaction of the individual they serve as the only means by which the carrier and spreader of infection may be detected.

It is unfortunate that circumstances prevented the direct cultural examination of four of the eight aborted fetuses of the vaccinated group. However, inasmuch as the act of abortion is induced not by infection of the fetus proper, but by pathologic changes in the placental membranes, the examination of and demonstration of the organism in the latter tissue is of primary importance. As will be noted in the outlines of examinations made we have been governed in our diagnoses by the presence or absence of infection of the placenta with *Bact. abortus* Bang. Of the 8 abortions occurring in the vaccinated group, 5 (or 62.5 per cent) were due to *Bact. abortus* infection; of the remaining 3 (or 37.5 per cent) one, cow 364, showed no evidence of Bang infection. In another, cow 533, the abortion occurred so early in pregnancy that the results obtained were very questionable, while in the third, cow 361, the abortion was viewed as probably resulting from infection with *Bact. abortus* Bang. The reason for this contention is based upon positive evidence of an active focus

udder of infection in the body and the knowledge that this individual had always been a strong positive reactor to the serologic tests.

Sixteen fetuses of the 19 abortions occurring in the control group were examined by direct culture, 2 were lost while another was too badly decomposed for examination. Of the 16 fetuses examined 11 showed positive and 5 negative evidence of infection with the Bang organism. Since the examination of the placenta checked in all instances with the results obtained by fetal culture, it may be stated with safety that 11 abortions were due to *Bact. abortus*, while 5 were not. Our knowledge of the causitive agent of the 3 remaining abortions is indefinite. Two of the abortions occurring in cows 138 and 374 were very probably due to Bang infection. This contention is supported by our knowledge of an active focus (udder) of infection in both animals and that one had aborted and the other later aborted. A survey of the bacterologic data thus far presented serves to emphasis two important and generally recognized points; namely, that all abortions are not due to the Bang organism, and the consequent probability of error in judging the efficiency of an immunizing agent solely on clinical manifestations. While no bacteriological technic, especially in a study of this kind, is infallible, it is the only safe method by which to determine the degrees of immunity produced. The final result, therefore, upon which the degree of immunity may be judged is 5 (or 11.9 per cent) abortions for the vaccinated group as compared to 11 (or 16.6 per cent) for the controls. These percentages do not include those abortions of questionable classification which were 4.7 per cent and 4.5 per cent respectively of the vaccinated and control groups. While the exposure of vaccinated animals to infection may have been open to question, we believe that the abortion rate and spread of infection in the control group, together with our definite knowledge that 36.6 per cent of all animals eliminated the organism, is sufficient evidence to conclude that the decrease in the number of abortions in the vaccinated as compared with the control animals is an index of the immunity induced rather than lack of exposure.

Abortions Due to Other Causes

Six, or 22.2 per cent, of a total of 27 abortions failed to show *Bact. abortus* Bang as the etiologic factor by a bacterio-

logic study, and 3, or 11.9 per cent, of the cases failed to show evidence of the Bang infection by serologic reaction. Although the recorded data refers only to results of the bacteriologic examinations for *Bact. abortus,* an extensive study was made especially of those abortions which occurred in animals giving negative serologic evidence of infection. Bacteriologic results, as well as examinations for probably mucor or vibrio involvement failed to reveal the causitive agent. Inasmuch as inquiry into herd management and physical examinations were likewise negative, we must, for the present, classify these abortions as occurring without demonstrable cause.

The Carrier Problem

The use of a viable organism, especially those of proven pathogenecity, as an immunizing agent, has always been viewed with misgiving, due to the ever-present danger of spread of the disease to non-infected individuals. This danger has limited the use of the vaccine to those herds showing a high percentage of natural infection. If the degree of immunity produced by the use of the living vaccine depends upon an ever-present low grade active infection the successfully immunized animal must be regarded as an ever-present source of danger as a spreader of infection. In order to compare this danger of the vaccinated as compared with the naturally infected animal a survey of the isolation of the organism from both groups is of interest. Of the 27 placentas examined following 34 normal calvings in the vaccinated group, 2, or 7.4 per cent, cows 136 and 366, showed the presence of the organism, as compared with 4, or 12.1 per cent, of 33 examinations of normal calvings in the control group. Including the number of isolations of *Bact. abortus* from the placentas of the abortions of each group we find that the organism was recovered in 22.2 per cent in the vaccinated as compared with 36.3 per cent of the control animals. The possibility of infection of the placental tissues with *Bact. abortus* in those cases where calving is apparently normal, even though the percentage may be small, serves to emphasize the need of isolation of all animals at the time of parturition.

While the spread of abortion infection through the uterine discharges may be successfully controlled by proper quarantine measures, the danger of milk-borne infection and its con-

trol is less clearly understood. Many investigators are of the opinion, based on experimental results, that calves fed upon infected milk do not harbor the organism for long periods of time and that permanent infection does not take place until sexual maturity. Whatever the danger of milk-borne infection may be, it is of interest to note that the number of animals eliminating the organism through this channel are not materially increased by the administration of the living vaccine, which shows 26 per cent as compared with 24.2 per cent for the control group animals giving off the organisms in the milk. A summation of the bacteriologic results shows that 30 per cent of the vaccinated and 42.4 per cent of the control animals eliminated *Bact. abortus* Bang by either one or both channels and thus acted as spreaders of the infection.

Before concluding the discussion of the carrier problem, we wish to refer briefly to the isolation of *Bact. abortus* Bang from those animals which fail to give positive evidence of infection to one or both of the serologic tests. While this condition is rarely met with, due possibly to disregard of negative animals, it is of sufficient importance to merit the attention of those who hope to succeed in controlling this disease solely by means of the serologic tests. It should be clearly understood that this data is not presented in any effort to discredit the serologic tests, but merely to call attention to their limitations, for we believe that successful control measures must be based upon a correct interpretation of a number of serologic reactions of each herd individual. Animal 366 was vaccinated July 12, 1923. She conceived at the fourth service and calved normally on January 30, 1925. On October 25, 1923, the agglutinin titre was partial at 1 : 200, with complement fixation complete at 0.1, 0.5, and 0.025. On September 9, 1924, the agglutinin titre had dropped to a partial at 1 : 25 with complement fixation still complete at 0.1, 0.05, and 0.025. On January 28, 1925, two days before the calving date, the agglutinin titre was negative throughout, while fixation remained positive. At parturition on January 30, 1925, *Bact. abortus* Bang was isolated from the placenta. Cow 143, giving a *partial* agglutinin titre at 1 : 25 and 1 : 50 on October 28, 1922, and thereafter negative to both tests, was found to be eliminating the organism in her milk on October 3, 1924. *Bact. abortus* was also isolated from her placenta following a normal calving on January 4, 1925. It is of interest to note

that this animal aborted during the following pregnancy but no evidence could be found indicating that the Bang organism was concerned. Animal 21 was found to be eliminating the organism in her milk on January 21, 1925. She was and had always been a negative reactor to both of the sera tests. Similar observations have been made by other workers. Hart and Traum[1] refer to such observations in their conclusions with the statement, "A correlation of the agglutination tests of the animals with the definite periods when *Bacterium abortum* was known to have been eliminated shows that this organism may be discharged from the body without its presence being suspected from the agglutination titre of the blood."

CONCLUSIONS

1. Although some degree of immunity toward *Bact.* abortus Bang is induced by the use of the living vaccine, it does not reduce the abortion rate to a desirable minimum and should never be used in other than badly infected herds.

2. Individual susceptibility to *Bact. abortus* Bang infection is extremely variable.

3. The use of the living vaccine did not increase the number of animals which eliminated *Bact. abortus* Bang.

4. Some animals may eliminate *Bact. abortus* Bang without showing serologic evidence of infection.

5. We have been unable to demonstrate that vaccination retards conception nor that increased sterility is directly associated with the use of the living vaccine.

We desire to have it clearly understood that in conclusions 3 and 5 the comparisons are between vaccinated animals and a group naturally infected with *Bact. abortus* Bang. Our experimental herd free of infection with the Bang organism, shows a much higher breeding efficiency than the vaccinated group. In our judgment the only way with our present knowledge to successfully control the disease resulting from infection with *Bact. abortus* is on the basis of the clean herd as determined by the serum tests.

REFERENCES

1. Hart, George E., and Traum, Jacob, The Relation of the Subcutaneous Administration of Living Bacterium Abortum to the Immunity and Carrier Problem of Bovine Infectious Abortion, *California Agricultural Experiment Station, Technical Paper No. 19*, 1925.
2. Buck, J. M., and Creech, G. T., Studies Relating to the Immunology of Bovine Infectious Abortion, *J. Agri. Res.*, 1924, xviii, 607.
3. Smith, T., and Little, R. B., Studies in Vaccinal Immunity Towards Disease of the Bovine Placenta Due to Bacillus Abortus, *Monograph 19, Rockefeller Inst. for Med. Res.*, 1923.
4. Fitch, C. P., and Boyd, W. L., Studies of the Value of Vaccine and Bacterins in Immunizing Cattle to Bact. Abortus (Bang), *J. Amer. Vet. Med. Assn.*, 1924, lxv, 407.
5. Fitch, C. P., and Lubbehusen, R. E., A Study of the Value of Whole Milk and Milk Sediment for the Isolation of Bacterium Abortus Bang, *Cornell Veterinarian*, 1926, xvi, 46.

ECHNICAL BULLETIN 44 NOVEMBER 1926

University of Minnesota
Agricultural Experiment Station
and
United States Department of Agriculture
Bureau of Agricultural Economics Co-operating

A Study of Dairy Farm Organization in Southeastern Minnesota

George A. Pond
Division of Farm Management, Agronomy, and Plant Genetics

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	5
Acknowledgments	5
Part I. History and description of the agriculture of the area	6
Location and description of area	6
Settlement and agricultural development of Steele County	10
Present type of farming	13
Part II. Unit expenditures of labor and materials for livestock, crop, and miscellaneous work	15
Expenditures of labor and materials for livestock	15
Dairy cows	16
Young dairy cattle	23
Swine	27
Poultry	33
Work horses	36
Colts	39
Expenditures of labor and materials for crops	41
Corn	42
Oats	45
Barley	47
Wheat	48
Small grain mixtures	50
Fall plowing	50
Tame hay	51
Alfalfa	52
Wild hay	54
Use of unit expenditure and labor distribution data in planning a cropping system	54
Relation of miscellaneous labor to crop and livestock labor	55
Planning the labor program of the farm	58
Tractor work	63
Part III. Application of unit expenditure and labor distribution data to organization of farm business	65
Principles of choice and adjustment of enterprises	65
Use of unit expenditure data in forecasting effect of enterprise adjustments	71
Summary	91
Appendix	95

ILLUSTRATIONS

Pag

Fig. 1. Location of area studied 2
2. Monthly precipitation at Waseca, 1920-24 and 10-year average 8
3. Percentage of crop acreage devoted to principal crops and units of productive livestcok in Steele County, 1859-1924 11
4. Animal units of productive livestock per farm in Steele County, 1860-1925 12
5. Distribution of man labor on 20 milk cows 25
6. Distribution of man labor on 17 head of young dairy cattle 27
7. Distribution of man labor on swine 34
8. Distribution of man labor on poultry 36
9. Distribution of man labor on horses 39
10. Distribution of man labor on 50 acres of corn 44
11. Distribution of man labor on 43 acres of oats 47
12. Distribution of man labor on 30 acres of barley 48
13. Distribution of man labor on 17 acres of spring wheat 49
14. Distribution of man labor on 24 acres of winter wheat 49
15. Distribution of man labor on 77 acres of fall plowing 51
16. Distribution of man labor on 23 acres of tame hay 52
17. Distribution of man labor on 11½ acres of alfalfa hay 54
18. Usual period for performance of field crop operations in Steele County 61
19. Day to day adjustment of fixed and shifting labor on a 208-acre farm 62
20. Exchange labor on a 220-acre farm 63
21. Distribution of labor and regular supply of labor (present organization) 73
22. Comparison of distribution of labor of present plan and first proposed plan with regular labor supply 78
23. Distribution of labor and regular supply (reorganization plan No. 2) 80
24. Distribution of labor and regular supply of labor (present organization) 83
25. Distibution of labor under proposed plan, regular labor supply, and differences between present and proposed plan 90

A STUDY OF DAIRY FARM ORGANIZATION IN SOUTHEASTERN MINNESOTA

By George A. Pond

INTRODUCTION

The dairy enterprise is now the largest single source of farm income in Minnesota. It has grown steadily in size and in relative importance since the settlement of the state. The number of dairy cows has increased 50 per cent in the last decade and 16 per cent during the period of this study. Dairying is dominant on more Minnesota farms than any other enterprise. Because of the importance of dairying in Minnesota agriculture and because of the changes in cropping systems and livestock organization that must be made to accommodate this expanding industry, a detailed study has been made of the organization and operation of a group of representative dairy farms in Steele County. Complete records of labor and material utilized for all crop and livestock production, as well as full information on all other details of the farm business, have been secured to serve as a basis for judging the relative desirability of different combinations and adjustments of enterprises for conditions that might be encountered in the area, and for studying efficient methods of conducting the enterprises in these combinations. The complete cost route method[1] was used in this study. A five-year period, beginning January 1, 1920, is included. The records were kept by the farmers whose business was studied, with the help and supervision of a route man employed co-operatively by the Minnesota Agricultural Experiment Station and the Bureau of Agricultural Economics of the United States Department of Agriculture.

Acknowledgments

This study was conducted co-operatively by the Division of Farm Management, Agronomy, and Plant Genetics of the Minnesota Agricultural Experiment Station and the Division of Farm Management and Costs of the Bureau of Agricultural Economics, United States Department of Agriculture. The author wishes to acknowledge the assistance received from the chiefs and staffs of these divisions in organizing and developing this study and in reviewing and criticising the manuscript. Special credit is due Andrew T. Hoverstad, of the Division of Farm Management, Agronomy, and Plant Genetics, for his assistance in collecting and tabulating the data and preparing them

[1] For the description of this method see Minn. Agr. Exp. Sta. Bul. 205, by G. A. Pond and J. W. Tapp; also issued as U. S. D. A. Bul. 1271. 1923.

for presentation. The thanks of the author and the departments supporting this study are due E. T. Helgeson, who served as route statistician on the Owatonna Farm Accounting Route, and the following farmers whose unfailing co-operation made the study possible:

Adams, Guy
Ballstadt, William H.
Belina, Charles M.
Boynton, William H.
Brush, George H. R.
Carstensen, John
Carter, A. J.
Case, Albert
Chambers, Alex
Chambers Bros.
Chambers, Frank R.
Chladek, Ben P.
Eskra, John
Fisher, Albert
Fisher Bros.
Fisher, Frank P.
Grandprey, Harry H.
Grass Bros.
Grass, Chris J.
Grass, Nels P.
Hartle, John & Sons
Hayes, Ralph
Hickok, Homer G.
Jones, Charles L.
Jones, Ray W.
Jones, William A.
Laughlin, John
Masche, William E.
Morford, Roy D.
Newhall, A. O.
Nielsen, Louis
Schafer, Barney & Son
Scott, H. G.
Vaux, Walter
Webb, Charles P.
Webb, Russell
Williams Bros.
Young, John

PART I. HISTORY AND DESCRIPTION OF THE AGRICULTURE OF THE AREA

Location and Description of the Area

Location

The farms studied are located in Steele County, near Owatonna, the county seat. This city had a population of 7252 in 1920. It is the principal marketing and business center of the county. Steele County is fairly representative of most of the dairy section of southeastern Minnesota in soil, climate, markets, and other conditions affecting the dairy industry. In this general area dairying is more widely practiced, the enterprise is more intensively conducted, and the type of farming is more uniform than in any other part of the state.

Climate

No data are available on climatic conditions in Steele County. In Table I are presented data on weather conditions for the five years of this study and for the ten-year period, 1915-24, from records kept at Waseca, fourteen miles west of Owatonna. Climatic conditions are fairly uniform over this section of the state. The monthly distribution of rainfall is indicated in Figure 2. Both amount and distribution vary considerably from year to year, but 75 per cent of the total precipitation occurs during the growing season. The first four years of the study were marked by less than normal rainfall. This resulted in short pastures and light second cuttings of hay and caused many new seedings of grass to fail. However, the deficiency

was least during the months when most of the field operations were performed, hence did not materially affect labor accomplishments.

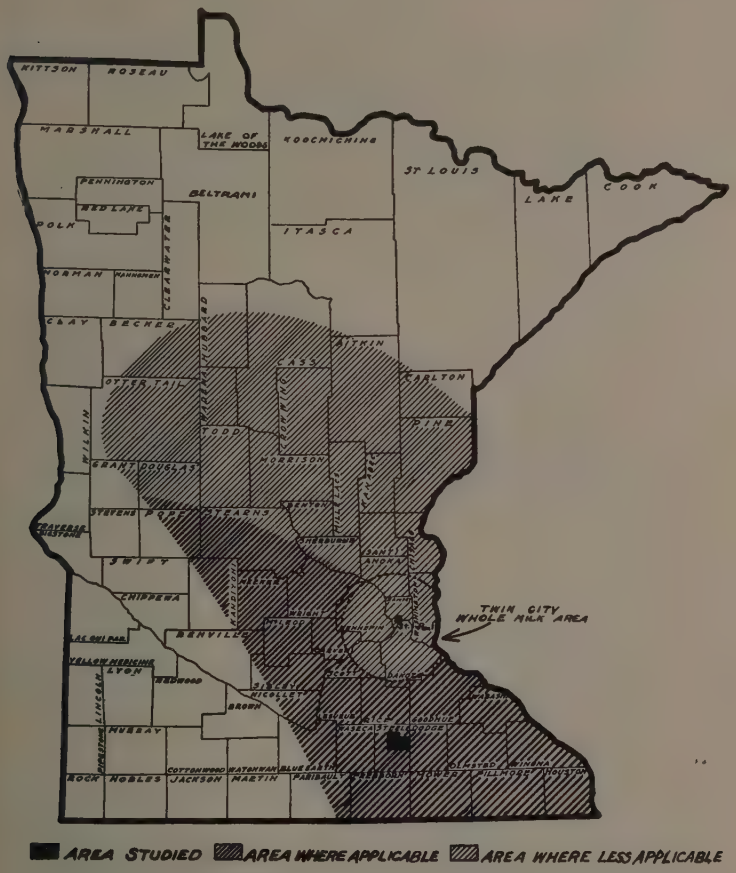


Fig. 1. Location of Area Studied

The type of dairy farming in Steele County is common to most of southeastern and east central Minnesota.

In 1923 corn and hay yields were greatly reduced by the drouth. The early part of 1924 was very dry and cool, and crops, especially pastures, started slowly. Abundant rainfall later resulted in fair hay yields and a very heavy small grain crop. The cool weather so delayed the corn crop that much of it failed to mature.

TABLE 1

CLIMATIC CONDITIONS AT WASECA, 1915-1924

	1920	1921	1922	1923	1924	10-year average
Maximum temperature	96	101	100	99	93	96
Minimum temperature	—22	—14	—22	—28	—37	—28
Mean annual temperature	44.7	48.1	46.5	45.8	42.7	43.9
Mean temperature April 1–Sept. 30.	61.6	65.8	64.4	63.6	59.0	61.6
Precipitation April 1–Sept. 30	12.25	20.74	15.24	16.68	27.73	21.44
Precipitation Oct. 1–March 31	8.31	3.64	8.78	5.46	5.81	7.30
Precipitation, total annual	20.56	24.38	24.02	22.14	33.54	28.74
Last killing frost in spring	Apr. 28	May 16	Apr. 22	May 17	May 25	May 11
First killing frost in fall	Sept. 30	Oct. 3	Oct. 9	Oct. 13	Sept. 30	Sept. 26
Frost-free days	154	139	169	148	127	137

* U.S. Weather Bureau, Minnesota Section.

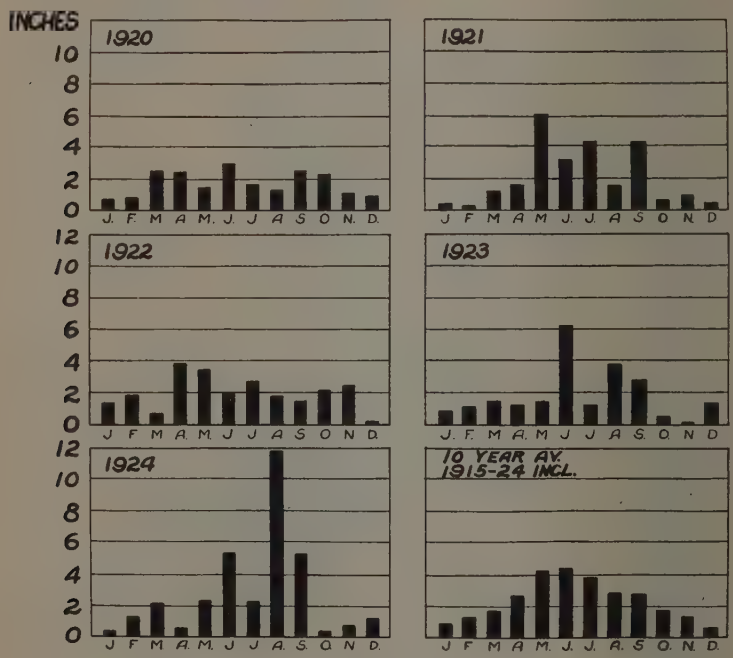


Fig. 2. Monthly Precipitation at Waseca, 1920-24 and 10-Year Average

The distribution of rainfall varies widely from year to year but most of the precipitation occurs during the growing season.

Soil and Topography

A rich black clay-loam soil with pebbly clay subsoil predominates in Steele County, as in all of southern Minnesota west of Steele County. There are also small areas of outwash sand and gravel along the streams. Most Steele County soils are well supplied with lime, but to the east of the county lies a large area of Old Gray Drift and loess, the surface soil of which is quite deficient in lime.

Steele county is level to gently rolling, with some steep hillsides along the water courses. The rolling land is naturally fairly well drained, but much of the level land is tiled to make possible its cultivation in wet years. The southern part of the county is open prairie, but the northern part and the river valleys were originally covered with heavy timber. Some good sized farm woodlots still remain. Most of this southeast dairy section was originally wooded.

Transportation and Markets

Steele County has excellent transportation facilities. The Chicago, Milwaukee, & St. Paul and the Chicago, Rock Island, & Pacific railroads furnish service to the north and south; and the Chicago & North Western to the east and west. Well improved state and federal highways, either graveled or paved, cross the county in both directions and are kept open throughout the year. County and township roads are dragged and in many cases graveled, so that most farms have access to markets by auto or truck during the greater part of the year.

Cream is the principal product marketed from these farms and is sold to co-operative creameries which specialize in the manufacture of high quality butter. The first co-operative creamery in the state was organized in 1890, a few miles south of the Steele County line. The movement developed rapidly and similar creameries were organized throughout this area. The twenty-three co-operative creameries in the county now absorb practically its entire dairy production. Except in the market-milk area around the Twin Cities, and in a cheese factory district in Dodge, Goodhue, and Olmstead counties, where about 25 per cent of the total milk is manufactured into cheese, practically the entire dairy product of this southeast dairy district and the central district as well, is marketed as cream through co-operative creameries. These creameries are federated into a large central marketing organization which sells their butter for them. Because of their more efficient organization and the high quality of their butter, these creameries pay higher prices for butterfat than the average creameries of the state. For the last fifteen years, according to the report of the State Dairy and Food Commission, Steele county creameries have paid farmers 8 per cent more for butterfat than the average price paid throughout the state.

There are four farmers' co-operative elevators and eight co-operative livestock shipping associations in Steele County. The latter handle practically all the stock shipped out of the county for slaughter. A co-operative poultry and egg marketing association, organized in 1924, is now serving the county. Because of their well organized marketing

facilities, farmers of Steele County and this southeast dairy section receive relatively better prices for their principal products than producers in other sections of the state.

Settlement and Agricultural Development of Steele County

History of Settlement

The settlement and development of Steele County is fairly typical of the entire dairy section of southeastern Minnesota. This was the first section of the state to be settled. The earliest settlers came in 1853, and the county was created and organized in 1855. The 1860 census reports 330 farms and a total population of 2863 (Table II). Railroads reached the county from the south and east in 1866. A period of rapid agricultural development followed. By 1880 practically all the land now in farms was in use. There has been some increase in the number of farms since that time with increases also in farm population, total acreage in farms, and percentage of improved land in farms.

TABLE II

NUMBER OF FARMS, LAND IN FARMS, VALUE OF LAND AND BUILDINGS PER ACRE, AND POPULATION OF STEELE COUNTY, 1860-1925*

Year	Farms in county	Acreage in farms	Average acreage per farm	Improved acreage per farm	Value of land and buildings per acre	Population
1860	330	57,911	176	29	$ 5.74	2,863
1870	831	118,377	143	57	16.68	8,271
1880	1607	243,362	151	120	18.96	12.460
1890	1590	236,988	149	134	18.58	13,232
1900	1801	263,371	146	126	42.62	16,524
1910	1824	262,555	144	123	60.98	16,146
1920	1860	259,215	139	115	137.05	18,061
1925	1997	264,061	132	...	108.53	

* U.S. Census data.

Changes in Acreage of Important Crops

Changes in the relative importance of the principal crops grown in Steele County since 1859 are shown in Figure 3. During the first years following settlement the few improved acres were devoted largely to feed crops. As the improved acreage increased and transportation and markets were developed, wheat increased rapidly in importance. By 1879 more than half the crop acreage was devoted to it. Up to this time new land was rapidly being brought under cultivation; since then there has been little expansion of the cultivated area. Continuous cropping with wheat led to decreased yields. Insect pests and diseases increased rapidly. The chinch bug was particularly destructive from 1885 to 1890. More diversification became necessary. The amount of livestock per farm, which had remained practically constant since 1860, more than doubled between 1880 and 1890. Feed crops replaced wheat. By 1889 the percentage of crop land in wheat dropped to 24.

Better yields of wheat followed this shift, and some reaction took place. The rate of livestock expansion decreased, and by 1899 nearly 39 per cent of the crop acreage was in wheat. Since that time livestock has steadily increased and wheat has been displaced by feed crops. Increasing damage by black stem rust is a factor of some importance in reducing the wheat acreage.

Corn and oats are the principal feed grains of the area, and their increase has followed fairly closely the expansion of the livestock industry. Barley, tho grown in part for sale during the earlier years, is now exclusively a feed crop. Hay has always occupied a large acreage. In the earlier years this was largely native grass and the yield was rather light. Often large areas were left uncut. As the livestock industry developed, the planting of higher yielding cultivated grasses and legumes enabled a smaller acreage of hay to support more livestock. The corn crop has also supplemented hay as a source of roughage. In 1924, 27 per cent of the corn crop was cut for fodder and 26 per cent was put into silos.

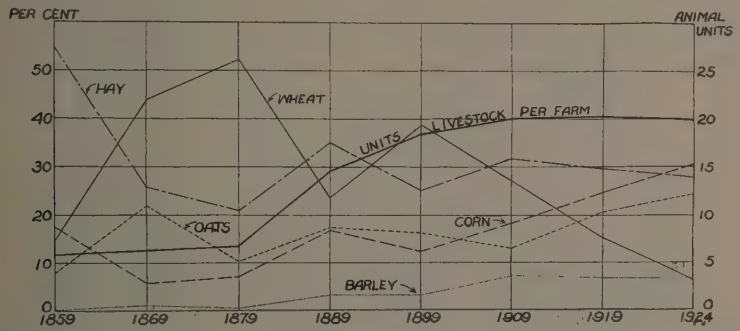


Fig. 3. Percentage of Crop Acreage Devoted to Principal Crops and Units of Productive Livestock in Steele County, 1859-1924

Wheat was once the leading crop in the county. With the shift to dairying it has steadily been replaced by feed crops.

In addition to the crops shown in Figure 3, small acreages of flax, rye, buckwheat, and potatoes have been grown. In recent years, peas and corn for canning have been grown to a limited extent, and in the last two years considerable acreages of sugar beets have been introduced on a few farms. The total acreage devoted to these miscellaneous crops has never exceeded 4 per cent of the total crop area.

The trends in crop production in Steele County are fairly typical of the southeast dairy section. In 1879 approximately 70 per cent of the wheat acreage in Minnesota was in this section. In 1924 scarcely more than 25 per cent of the acreage was included. The acreage was

less than one-fifth that of the earlier date. The shift was slightly more pronounced in Steele County because of the greater intensity of livestock production.

Changes in Number and Kind of Livestock

The trend of livestock expansion in Steele County is shown in Figure 4. As indicated in Figure 3, there was little change in the amount of livestock per farm up to 1880, when the definite shift from grain to livestock farming began. Before this time the stock was kept primarily to supply home needs. The amount of livestock per farm more than doubled during the next decade, and there has been a steady increase since.

The first cattle brought to Steele County were of beef or "dual purpose" breeding. Enough cows were milked to supply the home with dairy products, and any surplus butter made was sold or exchanged for groceries or other supplies. The calves were raised, and those not needed to maintain the herds were sold for beef. The first

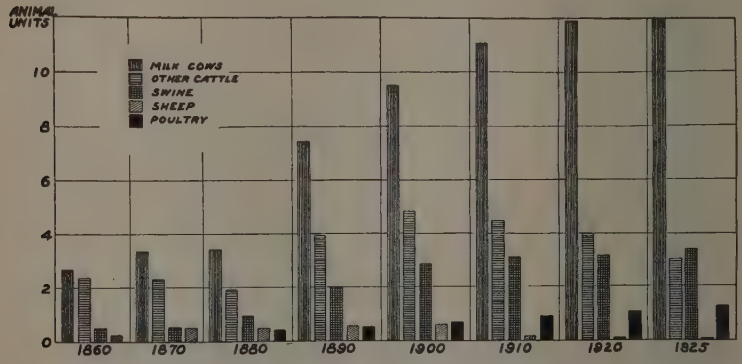


Fig. 4. Animal Units of Productive Livestock per Farm in Steele County, 1860-1925

The shift from grain to livestock farming started during the eighties. Since 1880 milk cows, swine, and poultry have increased steadily. Increased dairy specialization has resulted in a decrease in the number of other cattle and of sheep since 1900.

dairy product to be commercially manufactured was cheese. In 1872 there were six cheese factories in the county. Their output was small and by 1885 the number was decreased to three. These continued to operate until replaced by creameries in the nineties. In 1891 four creameries in the county were manufacturing butter. The number increased to nine the following year and to seventeen by 1894. With the coming of the creamery more attention was paid to breeding cattle for dairy production. The first cattle of specialized dairy breeds were brought to the county about 1880. It was not until after 1900, however, that the real shift to specialized dairying started. Co-operative creameries were affording a profitable outlet for dairy products and

there was a steady increase in both number of cows and intensiveness of dairy breeding. With the shift to the specialized dairy breeds, fewer calves were raised, as the dairy breeds produce beef of inferior quality. In 1900 there was one head of other cattle to each cow, but in 1925 there is only one head to 2 cows. Enough young stock is raised to maintain the herds, with some to sell as breeding stock. Cattle sold for meat are largely either veal calves or unprofitable cows culled out of the dairy herds.

The trend in swine production has followed the dairy enterprise quite closely. Hogs are to a considerable extent a by-product enterprise in a creamery district, utilizing the skimmilk left after the cream has been separated and sold. Large quantities of skimmilk for small pigs give the dairy farmer a decided advantage in pork production.

Sheep have never held a prominent place on Steele County farms. There have been small farm flocks, but with the expansion of the dairy industry the number has steadily declined.

Poultry has increased steadily since the first report, in 1880. Altho still a minor enterprise on most farms, there is an increasing tendency toward specialized poultry production. Like swine, poultry fit in well with the dairy enterprise and can use skimmilk advantageously.

Present Type of Farming

Size and Description of Farms

Thirty-eight farms are included in this study. Records were obtained from 12 farms for one year, from 5 for two years, from 5 for three years, from 6 for four years, and from 10 for five years—a total of 111 farm record years. The average size of farm was 186 acres, with a county average of 139 acres. One hundred twenty-nine acres were in crops; 47 in pasture; 7 in farmstead, roads, and lanes; and 3 in waste. Of the pasture, about a third is rotation pasture on land that has been cropped, the balance is rough or wooded land or land not sufficiently drained for regular cropping. Seventy-two per cent of this land is operated by owners and the rest by tenants.

No changes in ownership occurred during the period of this study except transfers from father to son. A relatively high percentage of ownership and greater stability of tenure characterize the dairy sections of the state. The average distribution of cash receipts from these farms during the period studied was cattle 52 per cent, swine 29 per cent, other livestock 6 per cent, crops 11 per cent, and miscellaneous 2 per cent.

Cropping Systems and Rotations

Feed crops predominate in Steele County. The relative importance of the crops grown on the farms studied and a comparison with the county as a whole are shown in Table III.

TABLE III

DISTRIBUTION OF CROP ACREAGE ON FARMS STUDIED AND ON ALL FARMS IN STEELE COUNTY

Crop	Farms studied*						All farms†
	Total acreage	No. of farms growing the crop	Acreage on farms growing the crop			Per cent of total crop acreages	Per cent of total crop acreages
			Average	Maximum	Minimum		
Corn	4682	111	42	93	17	32.7	29.1
Oats	3358	111	30	85	7	23.4	22.7
Tame hay ...	1780	103	17	47	1	12.4	12.9
Barley	1507	97	16	71	3	10.5	5.6
Wild hay ...	997	82	12	46	1	7.0	14.9
Wheat	813	63	13	42	1	5.7	9.6
Alfalfa	412	63	7	20	1	2.9	0.3
Sugar beets .	164	8	21	39	11	1.2	0.1
Flax	130	14	9	25	3	0.9	1.2
Miscellaneous.	479	106	5	27	1	3.3	3.6

* Average for 111 farm years, 1920-24 inclusive.

† Average for all farms in Steele County, 1920-24 inclusive.

The only crops grown primarily for sale are wheat, flax, sugar beets, and peas and corn for canning. Sugar beets have been grown only in 1923 and 1924 on the farms studied. The only recent changes in the cropping system are the introduction of sugar beets on a few farms and the rapid increase of the alfalfa acreage from 1 per cent of the total crop acreage in 1920 to 5.4 per cent in 1924.

No definite rotation system is practiced. About eleven acres of meadow and pasture per farm are broken each year and planted to corn. Of the rest of the corn, three-fourths follows small grain and one-fourth follows corn. Of the small grain, about two-thirds follows corn and one-third small grain. About half the small grain is grown in mixtures. Oats and barley is the most common mixture but oats is also grown with wheat. The latter mixture is commonly called succotash. These mixtures are fed without separating except when the price of wheat is high, then the wheat is often separated from the oats and sold.

Description of Livestock

The number and kind of livestock on the farms studied are shown in Table IV. The intensity of stocking on these farms and on the average farm in the county are compared. The farms studied are evidently more heavily stocked than the average. The larger number of young cattle as compared with cows on these farms is probably due in part to differences in classifying the two groups. These are largely high grade or purebred cattle of dairy breeding. Approximately one-third are registered purebreds. This fact may also account for the larger proportion of young cattle, as more breeding stock is raised in the purebred and high-grade herds. On one farm a few breeding cattle of beef breed were maintained. On two others, feeders were purchased and fed. Otherwise all cattle were of dairy breeding.

Most of the swine are kept for pork production, altho several excellent purebred herds are included from which considerable breeding stock is sold. A few small flocks of sheep are maintained. The poultry enterprise, tho a minor one on most farms, is being rapidly expanded. The flocks averaged 40 per cent larger in 1924 than in 1920. Horses are the principal source of motive power on these farms, altho tractors, also, are used on more than half. On one farm purebred draft horses were kept and considerable attention was paid to horse breeding, but on most farms only enough colts were raised to supply the needed work stock.

TABLE IV
LIVESTOCK ON FARMS STUDIED AND ON ALL FARMS IN STEELE COUNTY

Kind of stock	Farms studied					Average number per 100 acres	
	Farms reporting	No. of head	No. head on farms reporting			Farms studied	All farms
			Average	Maximum	Minimum		
Milk cows	111	1851	16.7	29	5	9.0	10.3
Other cattle	111	2033	18.3	47	1	9.8	4.4
Swine	111	4837	43.6	185	1	23.4	13.5
Poultry	111	16381	147.6	325	50	79.4	78.9
Sheep	16	158	9.9	34	4	0.8	0.6
Work horses	111	741	6.7	14	3	3.6	3.6
Colts	51	122	2.4	7	1	0.6	0.5

PART II. UNIT EXPENDITURES OF LABOR AND MATERIALS FOR LIVESTOCK, CROP, AND MISCELLANEOUS WORK

Expenditures of Labor and Materials for Livestock

The principal requirements for livestock production are feed, man labor, and horse labor. In addition to these, which can be measured in physical units, are such others as medicine, veterinary services, disinfectants, etc., that can be measured only in money values. The amounts used for each class of stock on the farms studied are shown on the per head basis except in case of swine and poultry. Labor and materials for swine production are presented on the basis of the amounts used to produce 100 pounds net gain in weight. One hundred birds is the unit for poultry. Except in case of young dairy cattle, the product of each class of stock is indicated in terms of physical units. Where joint production is involved, both products are given. As growing dairy stock are valued on the basis of pedigree and conformation rather than size, no attempt has been made to measure their production on a weight basis.

The amount of roughage fed to livestock does not include straw for either feed or bedding, altho it was used for all classes of stock for the latter purpose and for feed for horses and, to some extent, for

cattle. It was impossible to get an accurate measure of the amount used. Several classes of stock usually eat at will from the same stack. Often more is tramped under foot than is actually eaten. Even where fed in mangers, much is thrown out as bedding. Altho no record of amounts used is available, it should be kept in mind that practically all straw grown on these farms was either used for bedding or fed to stock. In using these data, allowance should be made accordingly.

In addition to showing the amounts used for each class of stock on each farm for one year and the average of all farms for each of the five years, standards for each class of stock are presented. The standards are based on the accomplishments of farmers ranking approximately in the upper 25 per cent in efficiency of production. They represent the attainments of the farmers who are practicing the most profitable methods in feeding and handling their stock. This standard is materially better than the average on the farms studied, yet it is easily within the reach of any farmer who follows the practices discussed in this section of the study.

Dairy Cows

Description of Enterprise

The cows included in this study are all of dairy breeding. There are two Ayrshire herds, one Jersey herd, and one Guernsey herd. The rest are practically all of Holstein breeding. A third of all these cows are purebred and the rest are largely high grades. They are maintained mainly for butterfat production, altho the sales of purebred bull calves and purebred and high grade heifer calves are a source of considerable income.

Most of these farmers raise their own cows. Of the additions to these herds during the five years, 89 per cent were heifers raised in the herd and 11 per cent were cows bought from other herds. The heifers freshened at from 24 to 30 months. The average milking life of a cow was about five years, altho some individuals, especially valuable purebreds, were kept as long as they continued to produce calves regularly. Each year an average of one cow in five was sold. The annual death loss was 2.1 per cent. Of the cows sold, half were sold for slaughter and half for use in other herds.

Winter dairying predominates on these farms. Sixty-one per cent of the calves are born in September, October, November, and December, and only 8 per cent in the preceding four months. The milk is separated on the farm, the cream is marketed, and the skimmilk is fed.

The amount of feed and labor used and the production per cow are shown in Table V. The expenditures for each herd are presented for 1924 but only averages for the other four years. The year 1924 was chosen because the most efficient production was obtained that

year. The labor includes not only the regular chores—milking, feeding, cleaning the barn, and bedding the cows—but also marketing cream and such occasional operations as caring for a sick cow or testing for tuberculosis. The production record is based on butterfat actually utilized. It includes butterfat sold as cream and butterfat in whole milk, cream, or butter used in the house, and whole milk fed to calves.

Variations in Amounts of Feed for Dairy Cows

The amount fed is varied by the farmer according to his judgment and the supply of feed available. In general, a cow is fed according to her milk production, as indicated in Table V, in which are included all the herds studied, with each herd year considered a unit. The grain and the roughage fed per cow increase as production increases. The amount of pasture used per cow is determined by the season and bears little relation to production. The feed used per pound of butterfat indicates some significant differences between the production groups. It is often assumed that the roughage in a dairy cow's ration largely provides for body maintenance and that the grain fed is primarily for production. In general, this table bears out this assumption. In all groups the grain fed bears an almost constant relation to butterfat production. The roughage fed, on the other hand, altho somewhat larger per cow for the higher producing cows is less per pound of butterfat as production increases. As the maintenance requirement is fairly constant regardless of the production, the higher producing cows are more efficient in converting feed into butterfat than the low producers. There are, however, exceptions to the general rule that cows are fed according to butterfat production. If there are a large number of heifers in the herd which have not yet come into full production and are still growing, as was the case on Farm 26, more feed, proportionately, must be fed. Nine heifers freshened in this herd in 1924 and 8 the previous year. On Farm 20 the feeds are high because a herd was put on the show circuit, and extra feeds were used to put it in show condition.

The price of feeds affects the amount to be fed. The light grain feeding in 1920 was partly due to the high price of grain in relation to the price of butterfat. By 1921 feed prices declined much more, relatively, than butterfat prices, and grain was fed more freely. The farmers using beet tops fed more succulent roughage per cow than those feeding corn silage alone. Beet tops had no market value and could not be stored conveniently for winter use. As a result they were fed so liberally that there was considerable waste. On Farm 31 silage was fed so liberally that much was wasted, but this was exceptional.

TABLE V

AMOUNTS OF FEEDS, LABOR, AND MATERIALS USED PER YEAR FOR A DAIRY COW, 1924

Farm No.	No. of cows per farm	Corn	Small grain	Mill feeds	Oil-meal	Tame hay	Wild hay	Alfalfa	Corn fodder	Silage	Pasture	Total grain	Total dry roughage	Man labor	Horse work	Vet. services and medicine	Milk production	Butter fat production
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	days	lbs.	lbs.	hrs.	hrs.		lbs.	lbs.
5	24.1	...	1243	...	...	2358	...	471	...	5706	176	1243	2829	90	11	$0.70	4712	147
7	15.9	...	293	...	...	543	...	...	1122	10146	178	293	1666	97	3	0.49	4249	150
34	13.3	...	81	...	...	662	722	923	226	5509	221	81	2533	85	9	0.26	4986	182
14	18.2	...	757	...	16	300	...	1760	631	6868	189	773	2691	178	4	0.06	5805	184
25	25.5	...	722	39	...	...	883	262	1716	18284*	181	761	2861	174	3	...	5629	188
9	24.0	...	1408	...	...	...	...	2374	333	8957†	169	1408	2707	169	6	0.52	6058	189
24	13.3	179	1462	180	...	879	...	1061	...	13888‡	159	1821	1940	192	7	1.67	5736	191
10	15.6	260	1499	...	...	381	...	760	...	9128§	189	1759	1141	179	7	0.24	5244	194
26	23.8	...	2071	...	...	1843	...	210	...	6416	174	2071	2053	162	4	0.19	6012	196
35	17.4	...	843	86	...	302	...	886	...	9212	199	929	1188	146	7	0.86	5025	206
28	13.6	...	1757	...	15	853	...	631	2143	6208	176	1772	3627	197	7	1.31	6035	207
13	13.2	...	1030	19	...	1547	...	1021	1140	6145	171	1049	3708	129	9	...	6246	213
6	18.7	...	1748	243	112	1409	...	502	...	7434	161	2103	1910	132	8	1.42	6305	215
1	16.8	...	1207	388	18	553	...	3595	...	8220	173	1613	4147	148	7	0.53	6279	221
20	12.8	...	2633	127	39	97	...	2016	468	8539	189	2799	2581	258	22	...	6560	225
23	18.0	...	1494	...	...	1979	223	...	446	7527	160	1494	2648	156	4	...	6453	231
21	29.2	165	1901	264	...	1132	166	1381	...	8717	193	2330	2679	153	5	0.62	7533	232
19	13.4	...	1309	693	...	1930	...	...	1048	6768	160	2002	2978	172	10	0.22	7318	251
31	8.0	...	2629	...	40	1247	...	878	750	13979	161	2669	2875	233	16	0.45	7927	260
17	12.2	20	992	180	...	1515	...	...	316	15945‖	181	1192	1831	221	32	0.30	5338	269
18	20.0	...	1595	...	89	847	...	1471	...	9713	151	1684	2318	131	10	1.71	8074	285
Averages																		
367	cows, 1924	31	1356	101	15	971	111	982	452	9137	177	1503	2316	158	9	0.55	6038	208
370	" 1923	329	1563	69	17	1338	48	633	450	9297	196	1978	2469	155	10	0.97	6435	213
372	" 1922	595	1262	80	29	1874	237	598	368	7368	188	1966	3077	157	6	0.51	5873	195
308	" 1921	508	935	202	50	1523	71	238	143	8000	184	1695	1975	194	9	0.86	4912	174
337	" 1920	269	694	251	59	1870	62	...	283	7456	162	1273	2215	172	13	0.57	4873	170

* Including 11,435 pounds beet tops.
† Including 3808 pounds beet tops.
‡ Including 5817 pounds beet tops.
§ Including 4405 pounds beet tops.
‖ Including 5400 pounds beet tops.

The amount and quality of pasture materially affect the grain and roughage used. The number of days that the cattle are actually on pasture, tho the best available, is an inadequate measure of the amount of pasture consumed as compared with other feeds. The cows on Farm 34 were on pasture the largest number of days. They received no grain or silage and only a small amount of hay—they depended almost entirely on the pasture. On Farm 35, reporting the next largest number of pasture days per cow, the cows received silage in addition to the pasture except for one month. On Farm 20 the cows received grain all but two months while on pasture, as well as some hay and silage.

The herds on Farms 35 and 20 probably received less feed per day from the pasture than the herd on Farm 34. On the other hand, Farm 19 reports only 160 days of pasture, but during this time the cows received very little supplemental feed. This 160-day period represents more feed than the 199 days on Farm 35 or the 189 days on Farm 20.

The extent of supplemental feeding while the cows are on pasture is an important factor in determining the amount of feed used. While on winter feed the daily ration is fairly constant. The amount fed varies with the length of the feeding season and the amount of summer feeding. In 1920, when grain feeding was lightest, less than 9 per cent was fed while the stock was on pasture; but in 1923, the year of heaviest grain feeding, 29 per cent was fed during the pasture months. Pastures were best in 1920 and poorest in 1923. The heaviest dry roughage feeding was reported in 1922, 1923, and 1924, when 17 per cent was fed during the pasture months. Only 10 per cent was fed in 1920 and 1921.

TABLE VI

RELATION OF FEED AND LABOR EXPENDITURES TO PRODUCTION OF BUTTERFAT

Production group	No. of herds	Average production of butterfat	Feed and labor per cow				Feed and labor per lb. of butterfat			
			Grain	Dry roughage*	Pasture	Labor	Grain	Dry roughage*	Pasture	Labor
		lbs.	lbs.	lbs.	days	hrs.	lbs.	lbs.	days	hrs.
Under 160..	23	137	1197	4865	181	160	8.7	35.4	1.3	1.2
160-189	25	177	1508	4742	181	183	8.5	26.7	1.0	1.0
190-219	35	204	1828	5313	182	170	9.0	26.1	0.9	0.8
220 and over	23	251	2130	6283	177	185	8.5	25.0	0.7	0.7

* Three pounds of silage is considered the equivalent of 1 pound of dry roughage.

The effect on total feed of supplemental feeding while on pasture is also brought out by a study of individual farms. The amount of feed is almost invariably higher when considerable supplemental feeding is practiced. On Farms 7, 25, and 34, having the lowest grain requirements per cow, no grain was fed while the stock was on pasture. On Farms 20, 21, and 31, having the highest grain requirements per cow, 26.4 per cent was fed while the cows were on pasture.

On the three farms reporting the lowest feeding of dry roughage, only 1.3 per cent was fed during the pasture season; but on the three farms reporting the highest dry roughage feeding, 18 per cent was fed while the cows were on pasture. Corresponding figures for the three high and the low silage feeding groups were 4.6 and 31.4 per cent. These differences are due to differences in both amount and quality of pasture available and in intensity of production. Heavier feeding is practiced when pastures are poor or limited in size, and also when cows are being pushed for high production.

Variations in Labor Expenditures for Dairy Cows

Size of herd.—Herds above the average in size received 24 per cent less labor per cow than those below the average. Milking is the only operation that varies directly with the size of herd. For most other operations the labor per cow decreases as the number of cows increases.

Use of milking machine.—The average man labor expenditure on Farm 21 was 182 hours per cow for the four years before the milking machine was purchased, and 153 hours in 1924, when a machine was used. The average labor expenditure per cow on Farm 18 was 142 hours before and 130 hours after the purchase of a milking machine. In both cases the cows were fed more heavily after the machine was purchased and their production was materially increased. This indicates that the saving in labor resulted from the use of the machine rather than from less intensive methods of care or feeding.

Production of herd.—In general, the labor expenditure per cow tends to be higher for high producing herds, as they are not only fed heavier but they receive more feed in summer when on pasture. They receive more care and attention than low producing herds. When measured on the basis of labor per pound of butterfat, however, the labor expenditure decreases steadily as production increases. The production per cow increases more rapidly than the labor.

Fitting and showing cattle.—The heavy labor expenditure on Farm 20 is partly due to the fact that the herd was shown at several fairs. A large amount of extra labor was involved in fitting and showing.

Variations in Production of Butterfat

Amount and kind of feed.—The higher producing cows receive more feed, especially grain, than the low producers. The data in Table V indicate a fairly close and direct relation between grain fed and butterfat produced. The kind of feed is also important. For example, the herd on Farm 18 was fed 2314 pounds of grain and 6028 pounds of dry roughage per cow in 1923, as compared with 1684 pounds of grain and 5556 pounds of dry roughage in 1924. Yet in 1924, in

spite of lighter feeding, the production of butterfat per cow was 285 pounds as compared with 256 in 1923. This heavier production was largely due to the difference in quality of the rations fed. In 1923, 72 per cent of the roughage was timothy and clover, 21 per cent corn fodder, and 7 per cent alfalfa. In 1924, 37 per cent was timothy and clover and 63 per cent was alfalfa. The nutritive ratio of the roughage in 1923 was 1 : 11.7 as compared with 1 : 7.9 in 1924. As the grain ration was of about the same quality both years, the nutritive ratio of the total ration was 1 : 7.3 in 1924 as compared with 1 : 8.6 in 1923.

The same tendency for a ration with a narrower nutritive ratio to increase production is indicated in a comparison of the average figures for 1923 and 1924—480 pounds less grain per cow was fed in 1924 as compared with 1923 and the roughage remained the same. In spite of a 24 per cent cut in the grain ration, the production of butterfat declined only a little over 2 per cent. The nutritive ratio of the average 1923 ration was 1 : 8.5 and of the average 1924 ration 1 : 7.5. This narrowing of the ration was largely the result of the substitution of alfalfa for roughage less rich in protein.

Condition and health of herd.—The low production of the herd on Farm 5 was largely due to disease. The general condition of the herd was lowered and, owing to failure to breed, the cows did not freshen regularly.

Quality of cows.—The quality of the cows composing these herds is an important factor affecting production, but its effect is obscured by variations in feeding practices. On Farm 18, for example, is a very carefully selected herd of high quality that is also very carefully fed. This herd has been built up through the consistent use of pure-bred sires of high producing strains and the careful selection of the progeny. Heifers from the highest producing cows are added to the herd and only those maintaining a high standard of production are retained. In each year of this study, 25 per cent of the herd was weeded out and replaced by promising heifers. In four years the production was increased from an average of 202 pounds of butterfat per cow to 285 pounds. The increase in the average production from 170 pounds in 1920 to 213 pounds in 1923 is also due, in considerable measure, to improving the quality of the herds through breeding and selection. The slight drop in production in 1924 is due to a material reduction in grain feed. The production in proportion to feed was larger in 1924 than in any previous year, indicating a steady improvement in the quality of the herds.

Veterinary Service and Medicine

The cash expense for veterinary service and medicine varies widely from farm to farm and from year to year. The item includes mineral feed. It is large on Farms 6, 18, and 24 because of the larger amount of mineral feed used. This item also includes disinfectants and fees for tuberculosis testing.

Standards for Dairy Cows

The following are suggested as standards for a cow of good dairy breeding producing 250 pounds of butterfat per year. In computing the labor item it is assumed that the herd contains at least 15 cows and that reasonably convenient facilities are provided for feeding and handling the herd.

Grain, pounds	1900
Hay, alfalfa or clover, pounds	2500
Silage, pounds	9000
Pasture, days	160
Man labor, hours	150
Horse work, hours	10
Cash costs (veterinary care and medicine), cents	75

Distribution of Labor on Dairy Cows

Figure 5 shows the distribution of labor by weeks on a dairy herd averaging 20 cows for the year. The shaded portion of each bar represents the regular daily work—milking, separating the milk, feeding and bedding the cows, cleaning the barn, etc.—the clear portion, time spent marketing cream, such extra work as selling a cow or caring for a sick cow, and any other work on cows done at irregular intervals. This distribution is typical for the community for a well managed herd. These cows freshened in September, October, and November. They were kept in the barn until about April 1. From then until May 20 they were allowed to run in the yard during the day. Up to this time they were on full winter feed. On May 20 the cows were turned out to pasture and received no further feed until August, when silage feeding was resumed. In September grain feeding was begun and in October, hay feeding. The cows were taken off pasture at the end of October and put on full winter feed. The labor demand was lowest in August and September, when more than half the herd was dry. As the cows freshened, the amount of labor increased rapidly. The cows were kept in the barn all the time after about December 1. The extra labor indicated by the clear portion of the bar was largely in marketing cream. By co-operating with neighbors, the time thus spent was considerably reduced.

In general, the distribution of labor on dairy cows fits in well with crop labor demands. There is some conflict at seeding time; but dur-

ing the rush of harvesting, threshing, and silo filling the cows require the least labor of any season of the year. From April to November, inclusive, the cows require only two-thirds as much labor per day as during the four winter months.

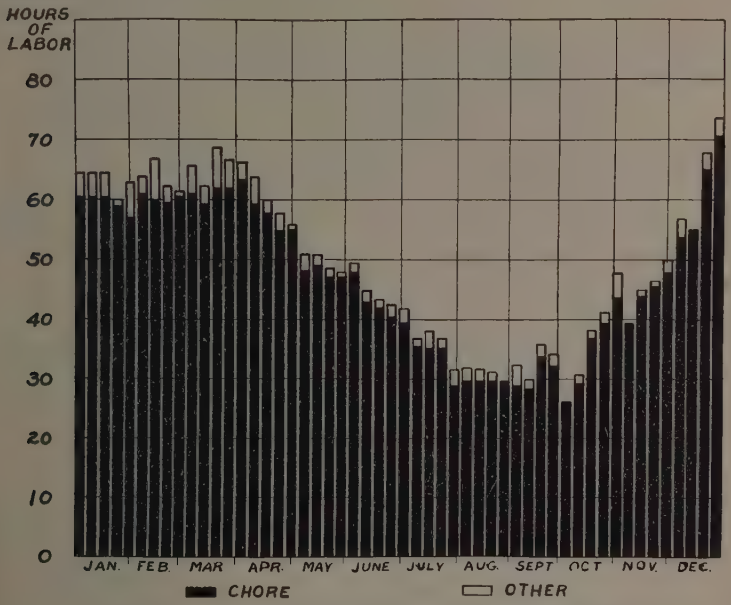


Fig. 5. Distribution of Man Labor by Weeks on 20 Milk Cows

Dairy cows make a heavy and continuous demand for labor. By practicing fall freshening it is possible to get the peak labor load in winter time and a slack period during the rush of harvest and silo filling.

Young Dairy Cattle

Description of Enterprise

"Young dairy cattle" includes all dairy cattle on the farm except the milk cows—all heifers up to the time of birth of their first calf, and all bulls. It may include a few steers or heifers that are intended for slaughter, but ordinarily the culls are sold as veal. Practically all the young dairy cattle raised are intended for the herd or for sale as breeding stock to other dairymen.

It is the usual practice on these farms to wean calves at birth or within a few days. Even calves intended for veal are not left with their dams more than a few days. All calves are fed whole milk immediately after weaning, and for calves to be vealed, whole milk may be continued until they are ready for market. Whole milk is gradually replaced with skimmilk for calves that are to be raised except that especially promising purebred calves may receive whole milk for several months. Eighty-seven living calves were dropped each

year for every 100 cows maintained. Of each 100 calves dropped, 5 died as calves and 1 before maturity, 43 were butchered or sold as veals, 4 were butchered or sold as yearlings or older, 12 were sold as breeding heifers, 10 as breeding bulls, and 25 freshened as heifers and were added to the milking herd. Practically all the grade bull calves were sold as veal and all purebred bulls for breeding purposes. Herd bulls are purchased from other herds, usually as calves. All purebred heifers are raised for sale or as additions to the herd. Approximately three-fourths of the heifer calves from the better grade cows are also raised for sale or for trial in the herd.

The amounts of feeds and of labor and materials used for these young dairy cattle are presented in Table VII. This class includes all ages of young cattle from birth to maturity as well as the herd bulls. However, the composition of the different herds is fairly uniform and the distribution by ages does not vary widely. No attempt was made to compute a unit of physical production for this group. The stock produced was the product, but its value varied so widely with the breeding and individuality of the animals that a weight figure would have little significance.

Variations in Feeds

As for cows, the feed for young cattle is varied according to the farmer's judgment and his general plan of herd management. On Farms 9, 20, 21, 23, and 31, a special effort is made to grow out the young stock to good size. All young cattle are fed grain continuously and are not turned on pasture until more than a year old. The better dairymen pay special attention to getting steady and rapid growth in both young bulls and heifers. The high feed consumption on Farm 20 is in part due to the fact that a purebred herd is maintained which is fitted for the show circuit. The cattle are heavily fed throughout the year, even while on pasture.

The lighter feeding of milk during 1920 and 1921 is due in some measure to the fact that the young cattle herds included relatively fewer young calves.

Variations in Labor

The labor spent on young dairy cattle varies with the methods of handling and the convenience of barn and lot arrangement. The labor on Farm 34 is kept down by very convenient facilities for handling the young cattle. On Farms 9, 19, and 23, on the other hand, lack of such facilities is a factor in high expenditures. In general, less time is spent in caring for the young cattle on farms maintaining low producing cows than on those having high producers. Purebred cattle receive more attention than grades. The size of the young cattle herd is also a factor affecting labor. In general, the larger the herd, the less the

labor per head. The high labor item on Farm 20 is due to the fitting and showing of the herd, as already mentioned. On account of the mixed composition of this class, none of these causes for variation stand out clearly in Table V.

Veterinary Service and Medicine

The charges for veterinary service and medicine for young dairy cattle are small. The most important items are testing for tuberculosis, and disinfectants.

Standards for Young Dairy Cattle

On account of the variability in composition of the young dairy cattle herds, it is difficult to set up standards of much significance. Separate standards for each of the various ages and classes included in this group would be much more valuable but can not be computed from data available. The standards given assume a herd of at least 15, including a herd bull, 7 calves, 5 yearlings, and 2 two-year olds.

Grain, pounds	500
Hay, alfalfa or clover, pounds	2000
Silage, pounds	4000
Whole milk, pounds	225
Skimmilk, pounds	1800
Pasture, days	60
Man labor, hours	40
Horse labor, hours	5
Cash costs (veterinary services and medicine), cents	20

Distribution of Labor on Young Dairy Cattle

The distribution of labor on a herd averaging 17 head is shown in Figure 6. These are part of the dairy herd for which the distribution of labor on cows is shown in Figure 5. The seasonal variation follows the same general direction as that on cows but fluctuates more widely. As has been mentioned, the calves are born in September, October, and November. This, together with the end of the pasture season for yearlings and two-year olds, results in a sharp increase in labor in November. The labor expended is practically constant until the cattle are turned out in the spring. During the summer, labor consists largely in the care of the bull, as all young cattle are on pasture by July 1. As with cows, the care of young cattle conflicts to some extent with labor on crops at seeding time, but throughout the rest of the crop season the labor is so light that competition is insignificant.

TABLE VII

AMOUNTS OF FEED, LABOR, AND MATERIALS USED PER HEAD PER YEAR FOR YOUNG DAIRY CATTLE, 1924

Farm No.	No. of head	Farm grains	Commercial feeds	Tame hay	Wild hay	Alfalfa	Corn fodder	Silage	Whole milk	Skim-milk	Pasture	Total grain	Total dry roughage	Vet. services, etc.	Man labor	Horse work
		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	days	lbs.	lbs.		hrs.	hrs.
7	7.3	64	...	399	...	500	533	3027	71	818	8	64	1432	$0.09	20	1
23	9.0	500	...	2018	...	...	...	3655	446	1795	52	500	2018	0.22	58	1
19	9.3	382	37	1313	...	...	84	3810	222	1743	49	419	1397	0.18	45	6
13	10.9	330	5	351	...	235	121	1445	465	1688	46	335	707		15	3
17	11.9	277	...	1314	50	...	188	7317	227	1963	64	277	1552	0.10	61	13
31	13.8	446	...	956	...	319	504	4952	42	2186	66	446	1779	0.11	34	4
35	14.4	158	...	425	...	...	875	3179	243	2976	32	158	1300	1.45	36	3
20	14.5	1086	18	553	...	1632	...	3006	372	4467	31	1104	2185		83	12
28	16.1	149	6	638	...	90	781	2479	231	575	30	155	1509	0.16	42	2
27	16.2	225	6	422	...	586	19	4171	167	1726	49	231	1027		31	1
18	17.3	290	7	655	...	840	507	4446	114	1683	65	297	2002	0.12	37	5
25	17.8	93	...	38	575	133	869	6540	414	1972	75	93	1615	0.11	47	7
14	18.0	313	...	500	...	720	357	3108	233	1894	60	313	1577	0.03	44	1
5	18.3	326	...	1742	...	334		3174	229	993	77	326	2076	0.07	29	3
1	20.3	185	8	388	...	1391	...	3306	270	2361	40	193	1779	0.16	37	4
9	20.4	491	5	...	197	1605	...	4140	79	3207	44	496	1802	0.42	56	4
24	20.6	275	...	389	37	319	146	4812	100	1828	62	275	891	0.10	33	4
10	23.9	295	...	258	258	218	...	3399	198	1590	33	295	734	0.13	34	2
34	26.0	54	...	...	433	448	38	3131	...	854	76	54	919	0.13	9	2
26	31.6	250	2	1175	126	...	16	3755	180	1553	67	252	1317	0.09	43	1
21	35.0	510	...	1343	...	421	...	4510	240	1763	50	510	1764	0.17	30	2
Averages																
373	head, 1924	316	4	688	99	484	203	3907	204	1862	53	320	1474	0.18	38	4
369	" 1923	431	9	741	145	284	316	3627	215	1840	67	440	1486	0.19	42	3
356	" 1922	363	10	1100	187	374	310	3174	58	2483	54	373	1971	0.08	48	2
357	" 1921	331	21	1203	114	81	124	3657	1	1708	85	352	1522	0.02	41	1
395	" 1920	344	37	1376	152	...	316	3500	67	1103	64	381	1844	0.21	22	2

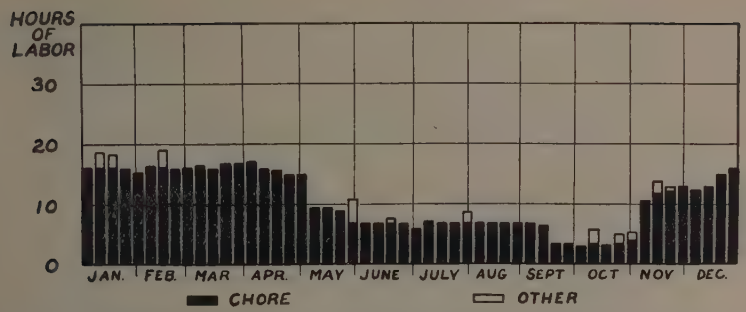


Fig. 6. Distribution of Man Labor by Weeks on 17 Head of Young Dairy Cattle

The labor expended on young dairy cattle shows a wider seasonal variation than for cows, but the general direction of the variation is practically the same.

Swine

Description of Enterprise

Swine are second only to dairy cattle in importance as a source of income on these farms. They offer a means of utilizing the large amount of skimmilk from the dairy herd as well as a market for a considerable quantity of corn and other farm grains. The availability of skimmilk as a protein supplement enables these dairymen to feed their hogs a well balanced ration without the necessity of purchasing large quantities of tankage and other expensive commercial feeds. This gives the dairyman selling cream an advantage in pork production over one who sells whole milk and over farmers who do not keep dairy cows. Swine are maintained primarily for pork production. There are several purebred herds from which considerable breeding stock is sold, but on most farms hogs are sold for slaughter. Duroc-Jersey and Poland China are the breeds most commonly used. Purebred boars are used almost exclusively and in most cases the sows, if not registered, would have been eligible to registry if records had been kept on the breeding stock. In only a few herds were grades or cross-breds to be found. The general quality of the breeding stock is very good.

Breeding practices vary quite widely. From 60 to 70 per cent of these farmers raise two litters per year with some of their sows. Seventy per cent of all pigs raised are farrowed in the spring and 30 per cent in the fall. There is a distinct advantage in having some fall litters to use the large amount of skimmilk available during the fall and winter; also because the weather is usually more favorable for farrowing than in early spring. If two litters a year are raised, the spring pigs are usually farrowed in March or early April. If only one litter is raised, farrowings are often delayed until May or even June. Gilts are commonly used for breeding purposes when only one litter is desired but more aged sows are generally used when two

litters a year are raised. On the average, 5 pigs per litter were raised to maturity or market age for the five years. The average was slightly higher in fall than in spring litters. Altho these farmers have a distinct advantage in raising pigs on account of the skimmilk available, this is in part offset in many cases by cold, poorly lighted, and poorly ventilated hog houses and by buildings and lots infected with disease and infested with parasites as a result of over-crowding and poor sanitation.

The average weight of hogs marketed was 219 pounds. Some farmers regularly feed their hogs to weights of 240 or 250 pounds, while others sell at about 200 pounds. The percentage of hogs marketed each month is as follows: January 7.2, February 6.6, March 6.8, April 9.5, May 11.9, June 5.1, July 3.6, August 2.8, September 3.8, October 11.4, November 13.9, and December 17.4. The bulk of the spring pigs are marketed during the last three months of the year. Only a few farmers succeeded in feeding out their spring pigs for the September market. The heaviest run of fall pigs is ready for market in May. That the sales during July, August, and September included a large number of heavy sows, is indicated by the fact that the average marketing weight was over 300 pounds. The amounts of feed and labor used for pork production are presented in Table VIII. Corn constituted about two-thirds of the grain ration. The small grain ration was largely oats and barley or mixtures of the two. The mill feed included standard middlings, flour middlings, and red dog flour. Pasture was used on nearly all farms. The pasture crops included alfalfa, rape, clover and timothy, and bluegrass. Some buttermilk is included with the skimmilk. The pork produced includes the net gain in weight of all hogs on the farm during the year. It is obtained by adding live weight of all hogs sold, or butchered for home consumption, during the year, and the weight of hogs on hand at the end of the year, and subtracting from this the weight of those on hand at the beginning of the year, and any purchased during the year. The figure obtained is net and covers death risk, as no allowance is made for hogs that died during the year. The feed per 100 pounds of pork produced included the maintenance feed for the breeding herd which produced the pigs actually marketed. Data for 1923 are presented instead of for 1924, as with other classes of livestock. The corn crop in 1924 was scarce and poor. As corn is the principal hog feed, more representative figures are obtained from a normal corn year.

TABLE VIII

AMOUNTS OF FEED, LABOR, AND MATERIALS USED FOR PRODUCTION OF 100 POUNDS OF PORK

Farm No.	Pork produced	Corn	Small grain	Mill feeds	Total grain	Tankage	Skimmilk	Pasture	Man labor	Horse work	Vet. service and medicine
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	days	hrs.	hrs.	cents
28	16,198	187	109	..	296	...	333	7	5.4	0.6	..
4	14,125	148	157	5	310	2.8	317	28	4.1	0.5	..
13	12,335	227	112	..	339	...	352	..	3.8	0.4	..
23	25,802	267	81	4	352	16.6	323	35	3.4	0.4	..
10	11,472	214	146	..	360	...	277	24	4.5	..	..
25	8,255	176	183	6	365	...	1154	24	10.7	1.2	..
20	9,999	337	41	..	378	...	106	62	6.4	1.1	..
5	11,610	315	39	..	384	...	836	14	4.6	0.9	..
31	31,628	223	162	..	385	4.3	144	27	2.9	0.5	16
6	27,869	220	168	3	391	5.2	297	19	3.8	0.6	..
27	10,719	245	128	19	392	...	296	51	7.2	0.5	..
36	20,849	330	57	6	393	12.4	22	31	3.8	1.6	..
18	22,228	284	144	..	428	...	400	36	4.5	1.0	..
22	18,607	196	233	..	429	...	442	70	5.3	0.6	..
9	9,675	295	170	..	465	...	1017	7	8.6	..	..
1	6,142	322	152	13	487	8.1	1099	28	10.2	5.2	..
21	55,664	284	217	2	503	6.6	200	32	6.7	0.6	11
26	13,080	363	196	2	561	...	844	21	5.6	0.1	..
14	8,967	365	240	..	605	...	693	9	10.6	2.2	..
15	20,742	316	245	50	611	...	411	36	6.3	0.9	9
24	10,803	337	297	..	634	0.9	475	16	6.7	0.6	1
Averages											
1923	17,465	266	161	5	432	4.3	377	29	5.4	0.7	5
1924	13,136	292	149	12	453	2.7	464	36	5.5	0.6	3
1922	13,668	320	130	12	462	0.8	358	29	5.4	0.5	3
1921	10,040	263	119	11	393	3.8	300	39	6.2	0.7	3
1920	11,184	279	93	13	385	2.5	290	20	5.1	0.5	7

Variations in Feed

Number of pigs raised per sow.—Generally less feed is used for 100 pounds of pork when large litters are raised. On Farms 4, 13, and 28, using the least, the average number of pigs per litter was 6.2. The average size of litter on Farms 14, 15, and 24, using the most feeds, was only 3.3 pigs. An additional factor affecting feeds on these two groups of farms was the number of litters raised each year per sow. In the low-feed group each sow raised two litters, while in the high-feed group only a third of the sows raised more than one litter. As the feed for the brood sows is charged against the pigs they produce, the more pigs each sow produces the less will be the charge per pig or per 100 pounds of pork produced.

Weight of breeding stock.—A factor in the amount of feeds on Farms 15 and 21 is the weight of the breeding stock. These are purebred herds raising considerable stock to sell for breeding purposes. The brood sows are largely aged sows weighing 500 to 600 pounds apiece. They are approximately twice as heavy as the gilts that are commonly used on farms where hogs are raised only for slaughter.

Practices with purebred herds.—In addition to the weight of brood sows, mentioned as a factor in increasing feeds, certain practices tend toward this result. In order to get the maximum growth, gilts are sometimes not bred to farrow till about eighteen months of age, while twelve months is the usual age in most herds. Extra feed is used while the purebred herds are being fitted for the show circuit. Fall litters are often sacrificed in order to have the sows available for showing in the fall, while all aged sows raise two litters each year if hogs are raised for slaughter. These factors contribute to the large amount of feeds on Farm 21.

Kind of ration used.—The amount of protein in the ration, and the kind of pasture used are important factors determining feeds. On Farm 31, 763 pounds of grain was required to produce 100 pounds of pork in 1920 as compared with 385 pounds in 1923, as shown in Table VIII. In 1920 the ration consisted largely of such fattening feeds as corn and barley. Bluegrass was used as pasture. Brood sows were fed corn exclusively and produced small, weak litters. In 1923 a grain ration 50 per cent richer in protein was used. Alfalfa pasture was substituted for bluegrass. Oats replaced corn for the brood sows and 6.4 pigs were raised per litter instead of 3.1. Almost twice as much pork was produced per 100 pounds of grain fed.

Quantity of feed available.—Skimmilk is necessarily fed when it is produced. It is used to best advantage when fed to young pigs. However, if only one litter a year is raised, there is only a short time when young pigs are available to utilize this skimmilk. The rest of

the year it is fed to more mature stock. Raising two litters a year results in a better utilization of this by-product of the dairy enterprise. If the hog enterprise is small and the dairy enterprise large, as on Farms 1 and 25, most of the skimmilk is fed to more mature hogs and in such quantities that they do not make the most economical use of it. On Farm 36, on the other hand, the relation of the dairy and hog enterprises is reversed and the skimmilk feeding is light.

Weights at which hogs are marketed.—On Farm 23 there were few pigs in 1922 and in order to market the available grain, the pigs were fed out to an average weight of 287 pounds. In 1923 there were more pigs and they were fed out to a weight of 206 pounds. All other conditions were practically the same. Approximately 20 per cent less grain was required to produce 100 pounds of gain with the lighter hogs.

Purchase of feeder pigs.—On Farm 6 more than half the hogs marketed were bought as feeders. As no feed for the breeding herd which produced them is charged against these pigs, the amounts are somewhat lower than they would otherwise be.

Variations in Labor

Size of herd.—One of the most imortant factors affecting the labor used to produce 100 pounds of pork is the amount produced per farm. The larger the herd the less the labor. Farms producing less than 10,000 pounds of pork annually use more than twice as much labor per 100 pounds as farms producing over 20,000 pounds. It takes comparatively little longer to feed 100 hogs than to feed 50.

Feeding conveniences.—On farms 13 and 26 the amount of pork produced, size of litters, proportion of spring and fall farrowing, and other factors affecting labor are quite similar. However, nearly 50 per cent more labor was used to produce 100 pounds of pork on Farm 26 than on Farm 23, where the convenient arrangement of hog house and hog lots was an important factor in labor saving.

Raising purebred stock.—On Farms 15 and 21 the labor is considerably higher than the average in spite of the advantages of large production and convenient facilities for handling and feeding. Considerable extra time is spent with these purebred herds in fitting the hogs for show, showing them to prospective purchasers, selling singly or in small lots, attending sales, and caring for the details of pedigrees and registration.

Hogging-off corn.—The low labor on Farms 31 and 36 was in part due to the saving of labor through hogging-off corn.

Veterinary Service and Medicine

Veterinary service and medicine are of very minor importance as cost items on these farms. On Farms 15 and 21 the whole herds were vaccinated. These were purebred herds from which breeding stock was sold. The expense on Farm 31 was largely for disinfectants, worm powders, and mineral feed.

Standards for the Production of 100 Pounds of Pork

Grain, pounds	375
Skimmilk, pounds	350
Pasture (alfalfa, rape or clover), days	30
Man labor, hours	4.0
Horse work, hours	0.5

These standards are for hogs raised for slaughter rather than for purebred breeding stock. Good sized litters should be raised, death losses avoided, and the desirable practices mentioned in previous paragraphs should be followed if these standards are to be attained. The figure for skimmilk is based on the amount likely to be available and the grain is adjusted accordingly, recognizing the fact that during a part of the year the skimmilk must be fed to heavy hogs, and also in varying quantities. With the best possible adjustment of the swine enterprise to the milk supply, the grain might be reduced still further. The estimate for labor assumes the production of at least 12,000 pounds of pork annually per farm.

Distribution of Labor on Swine

The distribution of labor on swine for a farm producing 12,000 pounds of pork a year is shown in Figure 7. The labor distribution is fairly uniform throughout most of the year. Reduced numbers following sales in February reduce the labor somewhat, but March farrowings increase it. During the summer pasture season, less than half as much labor is used. The fall farrowing, the first week in September, again increases labor. It continues to increase with the

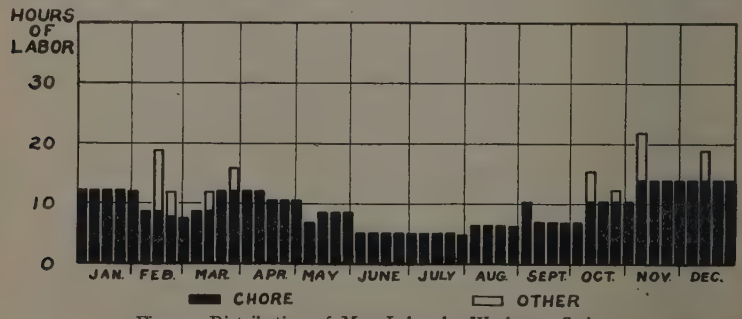


Fig. 7. Distribution of Man Labor by Weeks on Swine

By raising spring and fall litters the labor for hogs is spread fairly evenly throughout the year except during the summer pasture season, when it drops to about half the winter level.

heavier feeding of the spring pigs for October and November marketing. The fall pigs are weaned about November 1, thus increasing the labor still further. The "other labor" indicated by the clear portion of the bar is marketing work. This distinction is fairly representative for farms raising two litters per year.

Poultry

Description of Enterprise

There is a wide variation in the kind and quality of chickens on these farms as well as in methods of handling them. Both Mediterranean and American breeds are raised, often on the same farm. Poultry, like hogs, can utilize skimmilk advantageously, but there is considerable variation in the extent of its use. The amounts of feed, labor, and materials used per 100 mature chickens are shown in Table IX. In computing the average number of mature chickens, all birds under six months of age are figured as half of a mature chicken. The feed for the laying flock is combined with that for growing chicks so it is necessary to express the combined product in terms of both eggs and poultry. The feeds include only those actually fed. In addition to this the chickens forage about the farmstead and adjoining fields for a considerable part of their living. Much of the feed they pick up would otherwise be wasted.

Variations in Feeds

Feeds for poultry vary widely with practices and conditions on the farms. If a considerable amount of waste grain and other products is available, less marketable feed is required. If the farmer is satisfied with low production and allows the hens to forage for most of their living, they are fed very little. In general, there is a closer relation between feeds and meat production than between feeds and egg production. Little chicks can not forage for as large a proportion of their living as can mature stock. The farms producing more than the average quantity of meat used 55 per cent more feed per 100 birds than did those producing less than the average amount. The larger flocks also used somewhat more feed than the smaller, as the waste products to be picked up are less per bird.

Variations in Labor

The amount of labor tends to decrease as size of flock increases. It also decreases with added conveniences for handling the poultry. The amount of labor is much lower where the poultry work is done by men, as on Farms 13 and 36. Altho the time spent by women and children has been scaled down to a man-equivalent basis, it seems that, as the care of poultry is more or less a pastime, they do work that does not appear essential to the maintenance of the flock. If

men care for the poultry they pay more attention to providing labor-saving equipment. More labor is required where incubators and brooders are used. The use of such equipment accounts in part for the large amount of labor on Farms 6, 7, and 31.

Variations in Egg Production

Egg production varied with the care and attention given the poultry, the rations fed, the extent to which culling is practiced, and the type, quality, and adequacy of the housing facilities. On Farms 9, 13, 28, and 36 very careful culling and good feeding methods are practiced. Farms 13 and 28 have excellent poultry houses. Part of the difference in egg production is due to differences in the flock rather than entirely to the laying performance of the hens kept. As all roosters and all pullets or cockerels raised for sale are included, flocks having a large percentage of such birds will show lower egg production even tho the hens may be laying just as well as those in other flocks. On Farm 6, 5553 eggs were produced per 100 chickens, but as the hens constituted less than half the average number of chickens, the number of eggs per 100 hens was 11,500. Farm 24, having slightly more eggs per 100 chickens, had only 7300 eggs per 100 hens because the hens constituted a larger proportion of the whole flock.

Medicine, Disinfectants, etc.

One of the principal poultry problems on these farms is sanitation and disease control. The regular use of disinfectants is an important part of good poultry practice.

Standards for Poultry

It is difficult to work out standards for poultry that will be generally applicable because of the varying conditions under which they are kept on different farms. Where housing and sanitation are good and where flocks are as carefully culled and as well fed as they are on the farms where poultry received reasonably good care, for a flock of 200 chickens producing 6500 eggs and 300 pounds of meat per 100 birds, the following standards are suggested.

Grain, pounds	3500
Skimmilk, pounds	2000
Man labor, hours	175
Horse work, hours	4
Medicine and disinfectants	$2.00

In computing these standards it is assumed that the flock is given free range about the farmstead and fields.

TABLE IX

AMOUNTS OF FEEDS, LABOR, AND MATERIALS USED AND PRODUCTION PER 100 CHICKENS, 1924

Farm No.	No. of chickens		Corn	Oats and barley	Wheat	Mill feeds	Total grain	Skim-milk	Meat scraps	Man labor	Horse work	Medicine, disinfectants etc.	No. of eggs laid	Poultry produced
			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	hrs.	hrs.			lbs.
25	80		...	1565	...	...	1565			262	5.0	...	3000	64
1	135		737	924	...	...	1661	1670	...	184	8.0	...	4813	86
36	150		1189	1007	798	393	3387		...	96	1.0	$3.83	10120	—43*
34	150		3332	4884	...	177	8393	2208	100	174	38.0	0.83	3072	1081
6	165		105	4571	1096	...	5772	1417	...	300	3.0	1.54	5553	433
18	165		218	3434	193	30	3875	719	...	235	4.8	3.27	4424	286
23	175		...	887	3609	...	4496	...	...	227	...	1.42	5230	567
5	190		79	2454	2023	...	4556	1205	52	226	2.6	3.29	6865	116
19	220		576	1767	274	45	2662	555	...	172	3.6	1.25	4265	150
17	225		162	810	673	578	2223	538	...	254	6.7	1.42	5268	21
31	230		122	2034	1173	633	3962	953	43	269	4.0	2.52	6008	542
9	250		215	1670	...	...	1885	776	...	203	...	0.40	6736	166
28	300		1012	1758	1276	100	4146	1173	67	230	0.7	4.92	8571	195
14	300		...	3229	467	83	3779	899	...	158	...	0.46	2519	515
24	320		458	3609	152	125	4344	633	14	161	...	2.42	5708	304
13	360		581	1698	1736	39	4054	2367	31	54	1.9	...	6658	224
7	375		130	4030	1385	116	5661	1416	...	57	...	0.67	5106	159
Averages														
3790	chickens	1924	475	2455	936	140	4006	1056	19	178	3.5	1.66	5644	285
4062	"	1923	457	1830	986	105	3378	995	13	175	5.0	0.90	5285	291
2875	"	1922	320	886	518	81	1805	269	9	179	5.4	0.88	4810	493
2846	"	1921	80	770	541	14	1405	195	...	161	3.2	1.04	4296	291
2673	"	1920	930	1909	349	79	3267	763	...	342	3.4	2.17	5266	248

* Minus sign indicates loss of weight.

Distribution of Labor on Poultry

The distribution of man labor on a flock averaging 165 chickens is shown in Figure 8. The average number of laying hens during the year was 80; the production per 100 birds was 5553 eggs and 433 pounds of meat. The labor distribution is quite uniform during the year except during and following the hatching season. Altho the laying flock needs less attention when on free range, the care of the growing chicks more than offsets this decrease. As most of the work on poultry is done by women and children, the enterprise does not compete seriously for labor with the major enterprises of the farm.

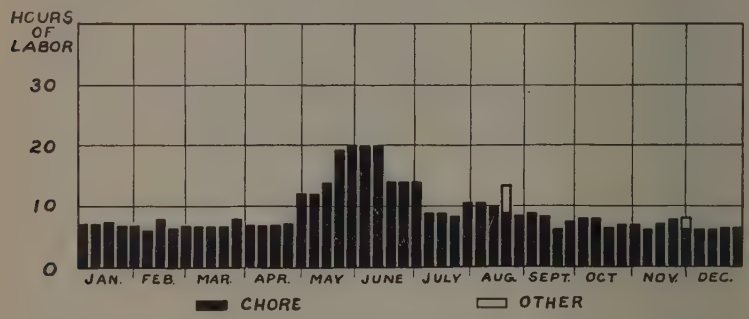


Fig. 8. Distribution of Man Labor by Weeks on Poultry

The labor used by poultry is quite uniform, except during the hatching and rearing season in May and June. Since the labor demand is low and most of the work is done by women and children, poultry does not compete seriously for the farmer's time.

Work Horses

Description of Enterprise

Horses are the main source of motive power on these farms but are supplemented by tractors on a little more than half of them. The horses are of ordinary grade stock, averaging in weight about 1350 pounds. Purebred horses are kept on only one farm; on other farms the horses are kept for work rather than for breeding purposes. Only occasionally are colts raised, and these only to maintain the supply of work stock. The amounts of feed and labor used for work horses are presented in Table X. All broken horses of working age, whether mares or geldings, are included. The data for colts will be presented separately.

Variations in Feeds for Work Horses

Amount of work performed by horses.—Altho other factors tend to offset it in individual cases, the more hours of work a horse performs annually the greater the amount of feed needed. The least grain is fed on Farm 7, where the horses work the fewest hours. It is lower than the average on Farm 17, altho the hours per horse are

highest there, because the horses were much smaller than the average and the higher number of hours does not represent an increased amount of work.

Kinds of feed.—The use of pasture saves both grain and roughage. Such a saving occurred on Farm 7, and of grain alone on Farm 25. A full analysis of the roughage figures is impossible, as no record of straw consumed is available. The roughage fed is low on Farms 17 and 24 because the horses receive considerable straw in addition. The roughage fed on Farms 13 and 31 is high because the horses receive no straw. Wild hay, corn fodder, and stover are usually fed more liberally than tame hay, as more or less waste is involved. Heavy roughage feeding may compensate for lighter grain feeding. This is apparent in a comparison of the average for 1924 with that of other years.

Variations in Man Labor on Horses

Amount of work performed by horses.—Where the horses work more hours per head, more man labor is spent on them. There are exceptions to this, as on Farm 5, where the horses are on pasture more than twice the usual period; or on Farm 36, where the horses are turned out in the fields in winter, fed hay in outdoor racks, and only the grain is fed in the barn.

Methods of care and handling.—Extensive use of pasture usually saves labor. However, on Farm 9, altho the average number of pasture days is high, the labor per horse is also nearly up to the average, because some of the horses are in pasture practically the whole summer; but the labor on the horses that were worked was enough to offset this. The practice of roughing the horses through the winter, as mentioned in the previous paragraph regarding Farm 36, also saves labor. It accounted in part for the small amount of labor on Farm 34 where, altho little pasture is used, the horses are turned out in the yard when not working.

Standards for Work Horses

The following standards are suggested for a 1500-pound horse working 1000 hours per year. In computing these it is assumed that the horses are working at the usual work done on these farms and in such units that their full capacity is realized. If tractors are available for heavier work, such as plowing, these standards may be reduced somewhat. The amount of roughage will vary with the kind used. In suggesting the feeds, it is assumed that some straw will be used in winter.

Grain, pounds	3000
Roughage, pounds	5000
Pasture, days	60
Man labor, hours	80
Cash costs	$1.25

TABLE X

AMOUNTS OF FEED, LABOR, AND MATERIALS USED FOR A YEAR FOR A WORK HORSE, 1924

Farm No.	No. of horses per farm	Corn	Small grain	Tame hay	Wild hay and fodder	Shredded stover	Pasture	Total grain	Total roughage	Man labor	Shoeing, Vet. services medicine	Total hours worked
		lbs.	lbs.	lbs.	lbs.	lbs.	days	lbs.	lbs.	hrs.		
7*	5.0	...	748	2488	931	489	122	748	3908	33	$0.18	516
14*	5.0	857	3372	2135	800	4424	25	4229	7359	114	0.06	638
24*	6.0	...	2176	975	1597	580	81	2176	3152	100	0.49	645
26†	11.0	403	2911	1610	2819	583	42	3314	5012	70	0.13	650
20	10.1	...	2647	2958	4762	...	94	2647	7720	88	...	708
27	6.3	374	1640	2426		1059	77	2014	3485	81	...	720
18	7.5	169	2803	3978	798	2073	97	2972	6849	83	1.38	758
21*	6.9	490	3101		5564		9	3591	5564	98	2.11	769
25	9.1	923		146	7671		108	923	7817	105	1.64	775
31*	6.2	80	2422	1904	2364	4472	30	2502	8740	73	0.25	790
35†	5.0	417	1990	4065			62	2407	4065	99	0.98	807
23*	6.0	62	2468	4228	2167		51	2530	6395	75	...	821
6*	6.8	...	3822	3957		1406	68	3822	5363	92	1.81	843
19	6.0	336	2694	3895	1815		51	3030	5710	102	2.45	850
34	6.0	1599	2537	365	3454		10	4136	3819	37	1.93	926
9	9.0	447	2132	1430	4927		102	2579	6357	79	0.44	956
1	5.7	540	1753	4031		2573	75	2293	6604	91	0.26	973
5*	6.2	554	2214	2986	1627		160	2768	4613	68	1.78	980
13	4.0	...	3263	4468	1784	1936	...	3263	8188	100	0.32	1002
36	5.2	1252	2595	4554	580		15	3847	5134	80	4.94	1096
10	5.5	818	1821	1321	3773		56	2639	5094	104	0.61	1129
28*	4.1	497	2590	1131	1691	2102	...	3087	4924	101	1.79	1154
17	6.3	114	2211	1593	1664	446	79	2325	3703	101	0.15	1170
Averages												
149 horses	1924	423	2326	2358	2523	847	66	2749	5728	85	0.98	870
152 "	1923	1196	1646	1873	1519	698	66	2842	4090	88	1.02	797
152 "	1922	2050	1537	2023	1640	1050	44	3587	4713	88	1.22	843
137 "	1921	1915	993	2855	1017	1114	58	2908	4986	97	1.23	830
144 "	1920	1398	1592	2447	1341	870	44	2990	4658	86	1.07	835

* Tractor used for drawbar work.

† Tractor used only for belt work in 1924, but available for drawbar work.

Distribution of Man Labor on Horses

The distribution of man labor on 6 horses is shown in Figure 9. It is much more uniform than that on the productive livestock. The horses receive some extra attention as the rush of spring work starts, but during the summer there is little variation. This distribution is representative for these farms. There is much more variation in the amount of labor spent on horses than in the seasonal distribution.

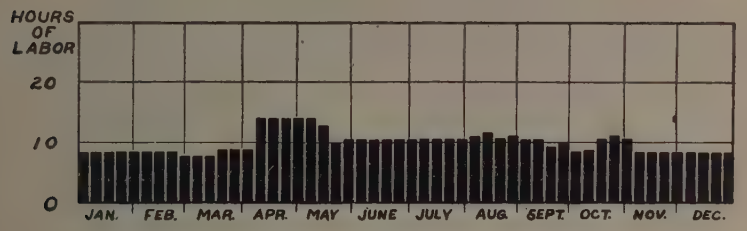


Fig. 9. Distribution of Man Labor by Weeks on Horses

Work horses demand steady regular attention throughout the year. Even when idle in winter they take only a little less of the farmer's time than during the busy summer season.

Colts

Description of Enterprise

Colts are maintained on about half the farms studied, but only a few are raised per farm. They are all grade colts except on Farm 20, and are raised for the purpose of replacing the work horses. Only on Farm 20 were colts raised for sale. The enterprise includes colts under one year, yearlings, two-year-olds, and even some unbroken three-year-olds.

Feed and Labor Used

The units of feed, labor, and materials used for colts are shown in Table XI. Because of the variation in age of the colts on different farms and varying methods of care, there is a wide range in amounts used. On Farms 14, 18, and 31, the colts are given considerable grain and grown to good size. On Farms 5 and 25, the colts run on pasture most of the year, receive little grain, and depend on straw for much of their roughage. The amount of grain fed on Farm 20 is low because considerable grain in the roughage is reported as fodder. No pasture is reported for Farms 1, 18, 24, and 25. On the first two the colts were on hand only during the winter season and on the other two the colts were born in 1924 and no pasture is charged the first season.

TABLE XI

AMOUNTS OF FEED, LABOR, AND MATERIALS USED PER YEAR FOR A COLT

Farm No.	No. colts per farm	Corn	Small grain	Tame hay	Wild hay and fodder	Shredded stover	Pasture	Total grain	Total roughage	Man labor	Vet. services and medicine
		lbs.	lbs.	lbs.	lbs.	lbs.	days	lbs.	lbs.	hours	
18	0.3	...	2323	...	...	4335	...	2323	4335	8	
24	0.6	...	1059	952	264		...	1059	1216	15	
1	0.6	...	1165	2536	...	1967	...	1165	4503	65	
5	1.0	...	492	1150	...		278	492	1150	18	$0.75
14	1.0	...	1520	1263	360	610	188	1520	2233	85	
36	1.1	407	851	1747	...		168	1258	1747	..	
25	1.4	246	336	694	...		...	582	694	38	
31	1.7	...	1091	884	...	167	211	1091	1051	12	
9	2.0	149	481	300	775		245	630	1075	59	
20	3.7	...	140	285	3784		263	140	4069	39	
26	5.4	73	430	285	394	207	159	503	886	29	
Averages											
19 head	1924	61	590	621	1020	232	178	651	1873	37	0.04
26 "	1923	225	375	265	345	370	208	600	980	26	
22 "	1922	500	367	1091	551	476	203	867	2118	15	0.63
27 "	1921	851	315	825	633	211	143	1166	1669	12	0.92
22 "	1920	493	339	678	545	843	161	832	2066	33	0.02

The labor varies even more widely than the feed. On Farm 36 the colts have the run of the farm, are fed with the work horses, and require so little extra care that no record was made of it. On Farm 14, the colts receive practically the same attention as a work horse. Colts require little of the farmer's time except in winter, and then so little as to be insignificant.

Standards for Colts

On account of the variability of the enterprise it is very difficult to compute significant standards for colts. On the basis of a careful study of the records, it appears that with the following amounts of feed and labor it is possible to raise a colt from birth to three years of age satisfactorily.

Grain, pounds	3000
Hay, clover or alfalfa, pounds	6000
Pasture	Three seasons
Man labor, hours	75

Expenditures of Labor and Materials for Crops

A knowledge of basic unit expenditures is essential to any study of the crop phases of farm organization. These expenditures include hours of man labor, hours of horse and tractor work, and quantities of seed, twine, and other materials used in the production of the crops considered. It is equally important to know the seasonal distribution of the labor for each crop and the probable days available for each of the crop operations. With these data available, the farmer is able to forecast in advance the effect of changes in his cropping system on his resources and on his returns.

On pages 96 to 108 in the appendix are tables showing the physical expenditures for the production of the principal farm crops grown on the farms studied, the expenditures for each farm for 1922, and weighted averages for all farms for each of the five years included in the study. The year 1922 was selected because general weather conditions were more nearly typical for the area than in any other of the four years. A wide range is apparent even tho these farms are in a locality where soil and climatic conditions are quite uniform. No attempt will be made to discuss in detail the causes for such variations.[2] However, one cause of variation is the extensive use of tractors. In these tables only hours of drawbar work for tractors are shown, as it is only at such work that horses and tractors are used interchangeably. The hours of tractor belt work (filling silos and shredding corn)

[2] For such a discussion see Minn. Agr. Exp. Sta. Bull. 205, "Farm Organization in Southwestern Minnesota" by G. A. Pond and J. W. Tapp; also issued as U.S. Dept. of Agr. Bull. 1271. Soil, climatic, and other conditions affecting farm operation are fairly comparable in these two areas and variations in physical costs are caused largely by the same factors.

have not been included. Many farmers hire the power for these operations. For the sake of uniformity all such work has been omitted.

In presenting the data for small grain, all small grain crops are combined. As they are largely raised for feed they are commonly grown in mixtures. Even when grown separately they are often harvested and threshed together and fed in mixtures, hence it was impossible clearly to separate labor between different crops, practices being fairly uniform. Any variations will be noted in the discussion of each crop. The yield is reported in pounds instead of bushels because of the mixtures.

In addition to showing the actual physical expenditures for these farms, standards are given which represent what may be reasonably expected under good management. They represent approximately the attainment of farmers who are found in the upper 25 per cent in the scale of efficiency as measured by low labor expenditure for a given operation. These are intended to serve as a standard by which any farmer may check the effectiveness with which he is utilizing his labor and power resources. In addition to time actually spent in the field, allowance has been made for time spent in going to and from fields, adjusting machinery, and making necessary field repairs to harness and equipment; resting teams; during showers; and any other ordinary interference necessarily incident to the operation.

Corn

Usual Practices in Corn Production

Two-thirds of all land for corn is plowed in the fall and one-third in the spring. Fall plowing is preferred, and is practiced as far as time permits, as it relieves the rush of spring work and makes possible earlier seedbed preparation. If wet weather prevents working the land with a disk or spring-tooth harrow to keep down weeds, the land is replowed. During the wet spring of 1922, 50 per cent of all corn land was replowed, but during the five years only about one-fifth of the total corn acreage was plowed twice. Practically all corn land is worked with a disk or a spring-tooth harrow prior to planting. The harrow is used more than the disk. About two-thirds of the land worked with a spring-tooth harrow is gone over twice and the rest once. When the disk is used, 43 per cent of the acreage is gone over once, 41 per cent twice, and the rest more often. The land is all harrowed before planting, 45 per cent two or more times. All planting is done with a two-row horse-drawn planter. Sixty per cent of the corn is checked in hills, the rest is drilled in. Most of the corn land is harrowed after planting, about one-eighth of it twice or oftener. Occasionally a field of corn is blind-cultivated immediately after planting, but cultivation is not ordinarily begun until the corn is above

ground. The average number of cultivations is 4.6. One per cent is cultivated only twice, 8 per cent three times, 38 per cent four times, 38 per cent five times, 13 per cent six times, and 2 per cent seven times. Both single and two-row cultivators are used.

During the period of this study 36 per cent of all corn raised was husked from the standing stalk and an equal quantity put into the silo, there being at least one silo on every farm. Thirteen per cent of the corn crop was husked and shredded; 8 per cent was cut, shocked, and fed in the bundle; 6 per cent was hogged-off; and 1 per cent was fed green. In 1923, when the drouth greatly reduced the yield, 45 per cent of the crop was required to fill the silos, and only 23 per cent was husked standing. There was a tendency during the five years to decrease the amount of corn husked and shredded and to increase the amount fed in bundles and hogged-off. Most of the corn husked standing was husked by hand, altho mechanical pickers were used on several farms.

Materials Used for Corn

The average amount of seed per acre for check corn on all farms is 8.5 pounds. It varies little from farm to farm. The average seeding for drilled corn is 14 pounds per acre, varying from 8 to 25 pounds on different farms. The heavier planting is intended only for fodder or silage. The average amount of twine used is 4 pounds per acre, the range being from 2 to 7 pounds. This variation is due almost altogether to differences in yields.

Standards of Corn Production

The following standards per acre are suggested for corn production. As already stated, the labor rates suggested are based on the accomplishment of farmers who use their labor most effectively. The seed rates are the usual rates in the community, and the amount of twine given is the amount used for a good average crop.

Operation	Equipment	Hours per acre		Acres covered in 10 hours
		Man	Horse	
Plowing	Gang plow and 5 horses	2.0	10.0	5.0
	Sulky plow and 3 horses	3.3	10.0	3.0
Disking	8-foot disk and 4 horses	0.5	2.0	20.0
Spring-tooth harrowing	2-section harrow and 4 horses	0.6	2.4	16.7
Harrowing	22-foot harrow and 4 horses	0.2	0.8	50.0
Planting		0.7	1.4	14.3
Cultivating	Single row cultivator	1.3	2.6	7.7
Cutting	3-horse team	1.6	4.8	6.3
Shocking		3.0	...	3.3
Filling silo		11.0	13.5	...
Husking (standing corn)	1 man with team	7.5	15.0	1.3
Husking and shredding		9.5	12.0	...

Seed for checked corn, 8 pounds per acre
Seed for drilled corn, 15 pounds per acre
Twine, 4 pounds per acre

Distribution of Labor on Corn

In the following table are shown the dates between which the different operations on the corn crop are commonly performed in the locality studied, and the usual days available for the operation. These dates may fluctuate from year to year, but their general sequence is fairly constant. The days available are computed by subtracting from the days in the period all Sundays and holidays and also an estimated number of days on which rain might interfere with the operation. This estimate is based on precipitation records for ten years interpreted in the light of actual rain interference during the five years of this study.

Operation	Dates	Work days available
Spring plowing	April 25–May 25	21
Disking and spring-tooth harrowing	May 5–May 29	18
Harrowing	May 5–June 2	18
Planting	May 9–May 30	14
Cultivating	May 25–July 14	35
Cutting	Sept. 3–Sept. 28	20
Shocking	Sept. 5–Sept. 30	20
Filling silo	Sept. 5–Sept. 22	12
Husking (standing corn)	Oct. 5–Nov. 30	42
Husking and shredding	Oct. 18–Nov. 10	18

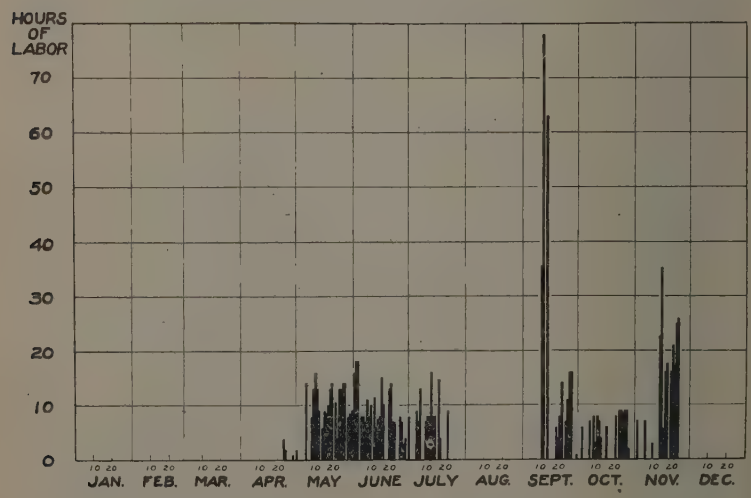


Fig. 10. Distribution of Man Labor by Days on 50 Acres of Corn

The corn crop uses large amounts of labor during May, June, and early July. Silo filling demands much labor for a short period and cutting should be done before or very soon after the first frost, but other harvesting operations may be spread over a considerable period of time.

The dates given do not include the extreme range of time during which the operations were performed, only the most usual period of performance and the time generally found most satisfactory, and can be safely used in planning the farm organization. For any one season adjustments must be made to the weather and seasonal progress of that year.

In Figure 10 is shown the seasonal distribution of labor on 50 acres of corn. Of this, 22 acres were husked standing, 15 were put in the silo, 9 were husked and shredded, and 4 were hogged-off. The steady, heavy labor demand during May was in part due to the fact that much of the corn land was replowed. Planting was begun on May 17 and finished on June 3. About July 1 work on tame hay interfered with corn cultivation, but this was made up later. The silo was filled on September 11, 12, and 14. The later work in September was cutting and shocking corn. Picking up loose ears and husking standing corn were the principal operations during October. Husking was completed during November. Shredding was done November 14 and 15. Except for the rather heavy labor load in May, this labor distribution is representative for the locality.

Oats

Usual Practices in Oat Production

Sixty per cent of the oat land is fall plowed, the rest is seeded without plowing. The land not plowed is usually corn land, and is worked with a disk or spring-tooth harrow in the spring, as is also the fall-plowed land. The unplowed land is usually either double-disked or gone over twice with the spring-tooth harrow. Most of the oat land is harrowed before seeding. One quarter is harrowed twice. Practically all the seeding is done with a three- or four-horse drill. The land is harrowed again after seeding. A seven-foot binder and four horses is the common unit for harvesting, altho on two farms the binder is drawn by a tractor. Shock threshing is the usual practice, altho a few farmers stack their grain each year.

Materials Used for Oats

There is comparatively little variation in rate of seeding. A few farmers use 3 bushels per acre and if the oats are to be used as a nurse crop for alfalfa seeding, 1½ bushels is used, but 2½ bushels is the standard rate. The average amount of twine used per acre is 3⅓ pounds, but this varies from 2 to nearly 5 pounds with varying yields of straw. The cash threshing charges per bushel were 5 cents in 1920, 4½ cents in 1921, 3½ cents in 1922, 3 cents in 1923, and 3½ cents in 1924, including any fuel furnished by the farmer.

Standards for Oat Production

The following standards cover the usual operations in oat production in this locality. The number and combination of these operations may be varied according to soil and weather conditions.

Operation	Equipment	Hours per acre		Acres covered 10 hours
		Man	Horse	
Plowing	Gang plow and 5 horses	2.0	10.0	5.0
	Sulky plow and 3 horses	3.3	10.0	3.0
Disking	8-foot disk and 4 horses	0.5	2.0	20.0
Spring-tooth harrowing	2-section harrow and 4 horses	0.6	2.4	16.7
Harrowing	22-foot harrow and 4 horses	0.2	0.8	50.0
Seeding	10-foot drill and 4 horses	0.5	2.0	20.0
Cutting	7-foot binder and 4 horses	0.8	3.2	12.5
Shocking		1.3	...	7.7
Stacking		3.2	4.5	...
Stack threshing		1.7	0.5	...
Shock threshing		3.2	4.5	...
Seed, 2½ bushels Twine, 3 1/3 pounds				

Distribution of Labor on Oats

In the following table are shown the dates between which the different operations on the oat crop are commonly performed and the usual days available for the operation during the period.

Operation	Dates	Work days available
Spring plowing	April 1–20	15
Disking and spring-tooth harrowing	April 5–25	13
Harrowing	April 5–May 1	19
Seeding	April 10–25	11
Cutting and shocking	July 12–25	11
Stacking	July 25–Aug. 10	12
Stack threshing	Sept. 25–Oct. 15	15
Shock threshing	July 25–Aug. 20	20

Work on the oat crop begins as soon as the ground can be worked in the spring. It is second only to wheat in earliness of planting. The dates suggested above may serve as a general guide in planning the farm operations, but must be adjusted each year to seasonal progress.

In Figure 11 is shown the distribution of man labor on 43 acres of oats. This labor is concentrated during three short periods—10 days of seedbed preparation and seeding in April, 7 days of harvest in July, and 2 days of threshing in August. This distribution is quite representative for the area.

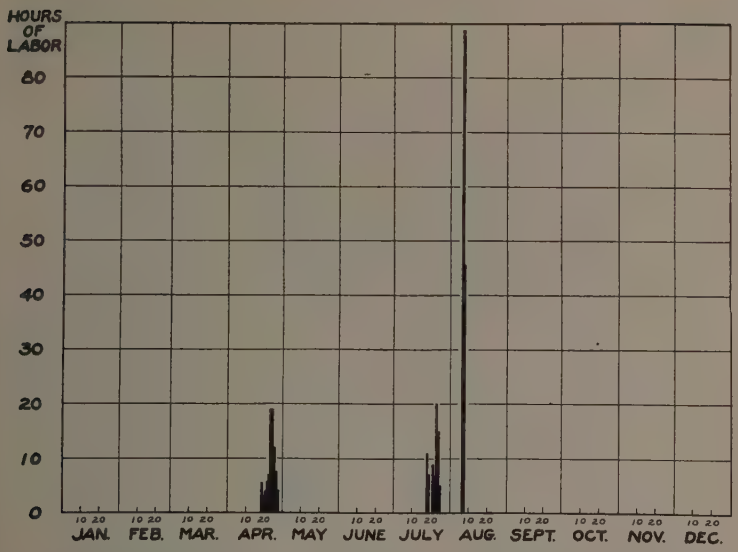


Fig. 11. Distribution of Man Labor by Days on 43 Acres of Oats

The oat crop requires attention during a comparatively limited number of days. This demand, fixed largely by weather conditions, allows little shifting, and the farmer must adjust his labor supply to it.

Barley

Usual Practices in Barley Production

Practically all land for barley is plowed. Two-thirds is plowed in the fall and the rest in the spring. The other operations are approximately the same as for oats.

Materials Used for Barley

The usual rate of seeding barley is 2 bushels per acre. The average twine consumption is 3 pounds per acre, but varies from 1½ to nearly 5 pounds. Barley is ordinarily threshed at the same rate as oats, altho occasionally the rate is half a cent higher per bushel.

Standards for Barley

The labor for barley would be practically the same as for oats. Two bushels of seed and 3 pounds of twine per acre are a fair allowance.

Distribution of Labor on Barley

The distribution of labor on barley is similar to that on oats. The same dates for the operation may be used except that barley matures a little more rapidly than oats and therefore may be sown a little later. It is usually the last of the small grains to be sown in the spring. In Figure 12 is shown the distribution of man labor on 30 acres of barley.

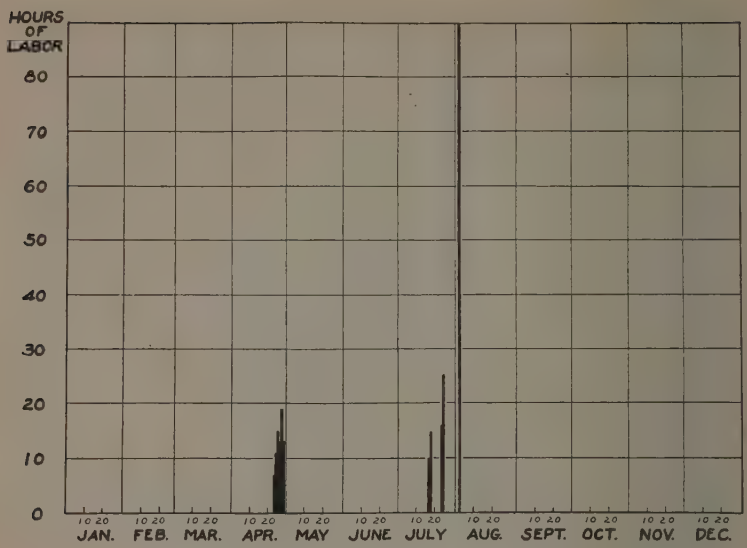


Fig. 12. Distribution of Man Labor by Days on 30 Acres of Barley

Barley is usually planted a little later than wheat or oats, but matures more rapidly, and is ready to harvest as early as any of the spring grains.

Wheat

Usual Practices in Wheat Production

For either winter or spring wheat the land is plowed in the fall and harrowed before planting, about half only once and the rest twice. For spring wheat the fall-plowed land is worked with either a disk or a spring-tooth harrow before planting. All wheat is sown with a drill. Other operations correspond quite closely to those for oats.

Materials Used for Wheat

The rate of wheat seeding varies from 1¼ to 2 bushels per acre; 1½ bushels is the most common rate with 1¾ next in frequency. The average amount of twine is 2¾ pounds per acre. The average threshing cost per bushel was 10½ cents in 1920, 7 cents in 1921 and 1922, and 5½ cents in 1923 and 1924.

Standards for Wheat Production

The labor rates for wheat are practically the same as for oats. The only difference is in the operations performed, which would vary for spring and winter wheat. One and a half bushels of seed and 2¾ pounds of twine should be allowed per acre.

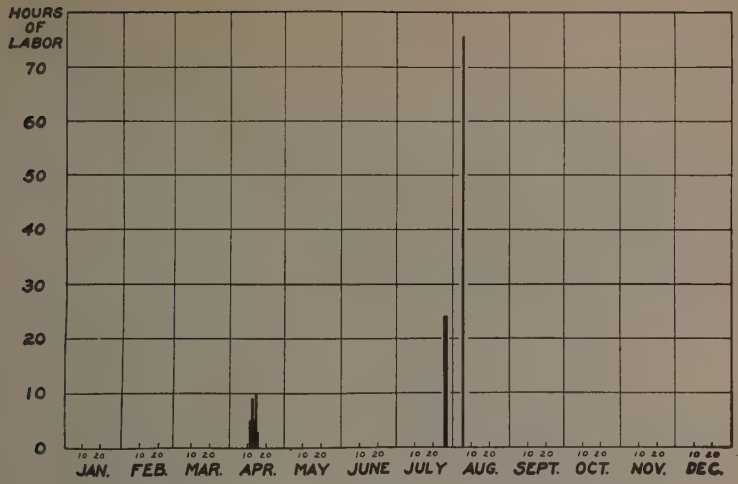


Fig. 13. Distribution of Man Labor by Days on 17 Acres of Spring Wheat

The distribution of labor on spring wheat resembles very closely that on oats and barley.

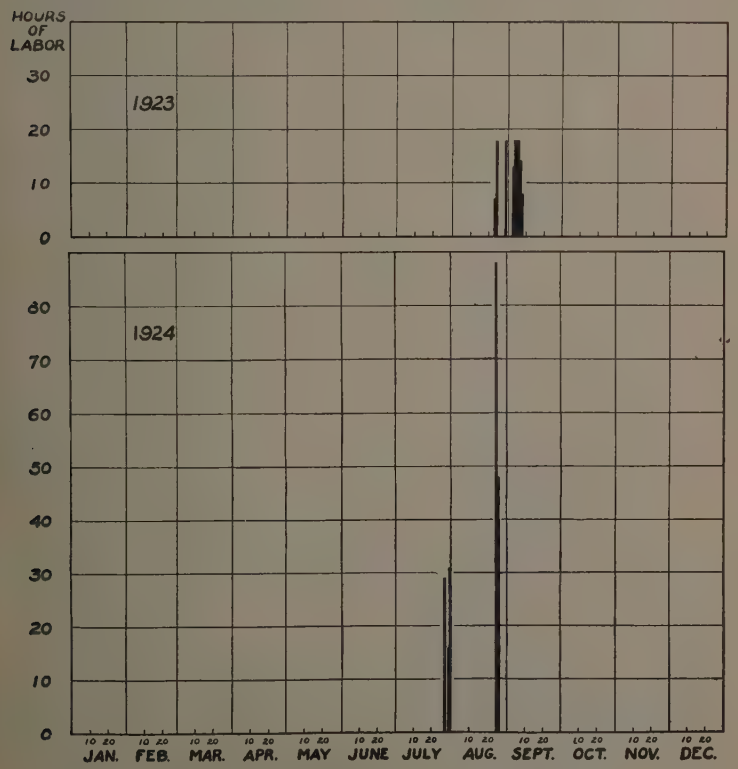


Fig. 14. Distribution of Man Labor by Days on 24 Acres of Winter Wheat

The winter wheat crop contributes to a more uniform season distribution of labor by avoiding the rush of spring seeding and distributing harvesting operations over a longer period.

Distribution of Labor on Wheat

The statement as to the usual time of performing the various operations on oats applies equally well to spring wheat. Spring wheat is the first crop planted in the spring and every effort is made to get it in as soon as the ground can be worked. Winter wheat is usually sown during the first half of September and is ready to cut about a week in advance of the spring-sown grains.

Figure 13 shows the distribution of man labor on 17 acres of spring wheat and Figure 14 on 24 acres of winter wheat. The proportionately smaller amount of labor for spring wheat is due to the fact that the land was plowed the previous fall and the labor does not appear here. All the plowing labor for the winter wheat is shown in the graph. The distribution of the fall work for winter wheat is representative for the crop in this locality. However, the harvesting operations are at least ten days later than normal. This graph is for 1924, when the harvest season was from 10 to 14 days later than normal. Winter wheat conflicts with silo filling and corn cutting, but relieves the rush of spring work and distributes the harvest over a little longer time.

Small Grain Mixtures

Two small grain mixtures commonly grown in this area are oats and barley and wheat and oats. The latter mixture is generally termed succotash. Altho barley ripens rather earlier than oats, by using an early variety of oats it is possible to secure a fairly even ripening. Cultural practices are about the same as for the same crops grown separately. From 2¼ to 2½ bushels of the mixture—half and half by weight of oats and barley—is the common rate of seeding. Succotash is sown at rates varying from 1½ to 2½ bushels per acre. The mixture varies from 32 to 80 per cent of wheat by weight. The most common seeding is 1 bushel of wheat and 1 of oats per acre. The average amount of twine used for either oats and barley or succotash is 3 1/3 pounds per acre, the same as for oats alone. Oats and barley are usually threshed at the same rate per bushel as oats alone, and succotash approximately one cent per bushel higher.

The standard labor rates for oats may be adapted to the mixed crops. The distribution of labor corresponds to that on the separate crops.

Fall Plowing

Attention was called to the fact that most of the plowing for corn and small grains was done the previous fall. Consequently the labor for the operation does not appear in the graph showing the seasonal distribution of labor. Figure 15 shows a representative distribution of man labor on 77 acres of fall plowing. The largest amount of the fall plowing is done in August after shock threshing and before silo filling. The rest is fitted in with the corn harvest.

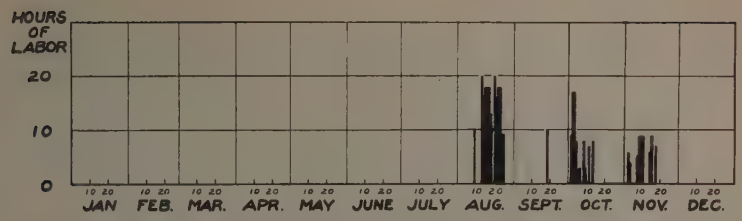


Fig. 15. Distribution of Man Labor by Days on 77 Acres of Fall Plowing

Early fall plowing is desirable from the standpoint of killing weeds. Fall plowing commences immediately after the grain fields are cleared and is fitted in around the threshing and corn harvesting operations.

Tame Hay

Tame hay, as the term is used here, includes red clover, alsike, timothy, and mixtures of these crops, usually a mixture of timothy and clover. Tame hay is seeded with small grain, either by mixing the seed in the drill box or by the use of a special attachment to the drill. Practically no labor is required in addition to that necessary for small grain seeding. If a clear seeding of clover is made, hay is cut only one year; if timothy is added, hay is cut the second and sometimes the third year or else the field is pastured the second or third year. Two cuttings of hay are made on about a fourth of the tame hay land. A second cutting is made for seed on a small acreage. The balance is usually pastured after the first cutting.

Practically all of the tame hay is raked into windrows and picked up with a hay loader or bunched with a rake and pitched on the wagon by hand. Considerable use is made of the side delivery rake. A small amount of hay is tedded before raking and some is cocked by hand. Practically all the tame hay is hauled directly from the field to the barn and unloaded into the mow with either a hay fork or slings. On fields distant from the farmstead the hay is sometimes stacked. The hay is hauled to the stacks with wagons and pitched off by hand. Too little stacking is done to justify the purchase of stackers.

Amounts of Grass Seed Used

The average amount of seed used per acre when clover is seeded alone is 10 pounds. For a mixture of timothy and clover, 3 2/5 pounds of timothy and 8 4/5 pounds of clover are used. This is sufficient for a good stand under ordinary conditions. Lighter seedings often result in a thin stand and there is little advantage in heavier seedings. Hot, dry summers, such as in 1923, are unfavorable for clover or grass seeding and result in a large percentage of loss irrespective of the rate of seeding.

Standards per Acre for Tame Hay

Operation	Equipment	Hours per acre		Acres covered in 10 hours
		Man	Horse	
Mowing, 1 cutting.....	5-foot mower and 2 horses.....	1.0	2.0	10
Raking, 1 cutting.....	10-foot rake and 2 horses.....	0.5	1.0	20
Hauling and stacking, 1 cutting (1½ tons yield)		4.5	6.0	..
Seed—Clover, 10 pounds Mixed, clover 8 pounds, timothy 4 pounds				

Distribution of Labor on Tame Hay

The harvesting period for tame hay ranges from the last week in June to the second week in July, according to the season. Clover is usually cut somewhat earlier than timothy or timothy and clover mixtures. Ordinarily the period of hay making is not more than two weeks, during which approximately ten days are available for hay making. Delay in cutting after the hay reaches the proper stage of maturity results in considerable loss in quality. The time for the second cutting of tame hay varies more than for the first, but is usually between August 20 and September 10, altho it is sometimes delayed until later in September.

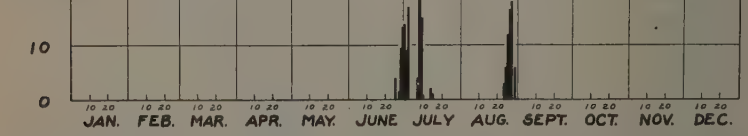


Fig. 16. Distribution of Man Labor by Days on 23 Acres of Tame Hay

Tame hay demands large quantities of labor for a short period of time. The first cutting competes with corn cultivation for the farmer's time and the second in a much less significant degree with fall plowing and silo filling.

In Figure 16 is shown the distribution of man labor on 23 acres of tame hay. A second crop was cut on the entire acreage. The seasonal distribution of labor on tame hay is fixed within rather narrow limits by weather conditions and they can be shifted but little without sacrificing the quantity or quality of the hay produced.

Alfalfa

Usual Practices in Alfalfa Production

During the earlier years of this study alfalfa was seeded alone. The land was plowed in the spring and worked with a disk or spring-tooth harrow during the summer to keep the weeds down. The alfalfa was seeded early in August. Usually the land was limed and the seed

inoculated. In more recent years the seed has been sown with small grain as a nurse crop. Practically as satisfactory results have been obtained without losing the use of the land for a year.

The practices in putting up alfalfa hay are very similar to those described for timothy and clover. More use is made of the side delivery rake and a larger proportion of the crop is turned over with a tedder. More of the alfalfa is cocked by hand. Practically all the alfalfa is hauled into the barn. Two cuttings are made on the entire acreage and in most cases three. Sometimes the third crop is pastured. If the second cutting is rather late, no third cutting is taken off.

Seeding Rates for Alfalfa

The average rate of seeding alfalfa is 11⅓ pounds per acre, varying from 8 to 17 pounds. In later years seeding was slightly heavier. Twelve pounds per acre is enough in most cases.

Standards per Acre for Alfalfa Hay

These rates were computed for a yield of 3½ tons per acre. No allowance is made for tedding or cocking, as these operations are performed so irregularly. About one half of a man hour and one horse hour may be allowed if the alfalfa is tedded and one to two man hours per acre for cocking.

Operation	Equipment	Hours per acre		Acres covered in 10 hours
		Man	Horse	
First cutting				
Mowing	5-foot mower and 2 horses	1.0	2.0	10
Raking	10-foot rake and 2 horses	0.5	1.0	20
Hauling		4.5	5.5	..
Second cutting				
Mowing		1.0	2.0	10
Raking		0.5	1.0	20
Hauling		3.2	4.5	..
Third cutting				
Mowing		1.0	2.0	10
Raking		0.5	1.0	20
Hauling		2.5	3.0	..

Distribution of Labor on Alfalfa

There is a wide variation in the time of cutting alfalfa. In some years the first crop is cut the first week in June and in others not till the third week. Even wider variations occur in the second and third crops. If only two crops are cut, both cuttings are somewhat later than if there are three cuttings. The most common dates for each of the cuttings and the days available during the period are indicated below.

First cutting	June 12 to June 23	7 days
Second cutting	July 13 to July 28	10 days
Third cutting	September 1 to September 24	14 days

Figure 17 shows the distribution of man labor by days on 11½ acres of alfalfa cut three times. The first and third cuttings interfere with work on the corn crop and the second cutting with small grain harvest. Because of the high value per ton of alfalfa hay and its importance in the dairy ration on these farms, alfalfa takes precedence over other crops and the labor organization is so adjusted as to make the labor available when necessary even at some sacrifice on other crops.

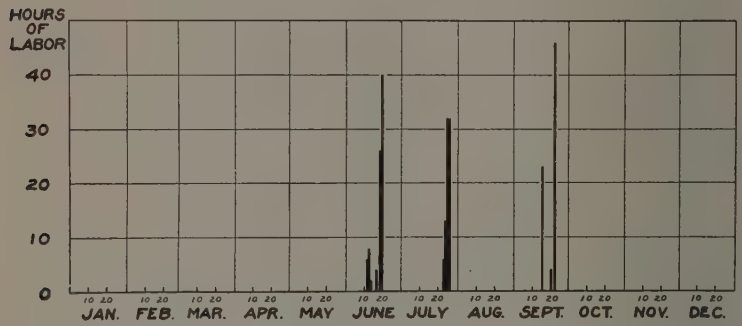


Fig. 17. Distribution of Man Labor by Days on 11½ Acres of Alfalfa Hay
Alfalfa demands large quantities of labor for short periods of time. It competes for the farmer's time during corn cultivation, small grain harvest, and corn harvest.

Wild Hay

Wild hay is not an important crop on these farms. It is grown largely on low land which is too poorly drained to produce other crops satisfactorily. It is handled very much as is tame hay, but is usually cut later, when the weather is more favorable for curing. It is seldom cocked or tedded, as it is less easily damaged by rain than tame hay. The time of cutting varies from late June to October, altho most of it is cut between June 24 and July 28. Wild hay deteriorates less rapidly after it is ready to cut than the tame grasses, hence it is possible to shift the time of cutting considerably in order to avoid conflict with more pressing work.

Use of Unit Expenditure and Labor Distribution Data in Planning a Cropping System

The actual expenditure of labor and materials per acre varies widely from farm to farm. This is evident from the foregoing discussion of crops and from a study of the crop labor tables in the appendix. Low labor expenditures are usually associated with large implements; large power units; experienced, able-bodied workers; balanced power and equipment units; large fields conveniently located; and careful planning of the labor program to avoid loss of time between tasks.

A farmer using the standards in planning a labor program should make allowances for his inability to use any of these methods of labor economy.

The suggested dates for the various crop operations indicate the sequence of the operations rather than exact dates for any given year. Each year's operations are speeded up or retarded according to the season. These data, with the labor distributions, indicate the competition between the several crops for the farmer's time at different periods of the year. The days available represent the maximum time that may be safely depended on for any particular operation. By computing the total labor for the acreage of crops planned and comparing it with the days available, the farmer can determine whether his labor supply is sufficient to meet the demands at all times or whether he must either change his plan or hire additional labor to handle the peak loads.

Relation of Miscellaneous Labor to Crop and Livestock Labor

Classification and Description of Miscellaneous Labor

The labor data presented thus far include only field labor on crops and direct labor on livestock. In addition, on every farm there is more or less indirect labor on both crops and livestock as well as a considerable amount of miscellaneous or maintenance work pertaining to the farm as a whole. For the purpose of this study this miscellaneous labor is divided into manure hauling, miscellaneous or other work on crops and on livestock, and maintenance labor.

Manure hauling.—Approximately 20 per cent of the crop area on the farms studied is manured each year, the average rate of application being slightly less than 10 loads per acre. There is a considerable range in size of loads, the average being approximately 75 bushels, weighing slightly more than a ton. Sixty per cent of this manure is hauled between November 1 and May 1, when most of the stock is in the barn. The custom on many farms is to haul out the manure each day. About the same quantity is hauled out each of these six months, 19 per cent being hauled in May. As most of the manure was applied to land to be planted to corn, this work represents the hauling out of the winter's accumulation to be plowed under for corn. Little manure is hauled during June, July, September, and October. Most farmers clean up their yards in August in the interval between shock threshing and silo filling. Except in May, manure hauling does not seriously interfere with direct labor on crops. Table XII shows the hours of man labor and horse work spent in manure hauling, with other significant facts regarding the operation.

TABLE XII

MANURE HAULING, 1922

Farm No.	Crop acres per farm	Animal units per 100 crop acres	Hours of labor		Loads hauled	Acres covered	Hours per acre		Loads per acre	Per cent of crop acreage covered
			Man	Horse			Man	Horse		
36	93	30	106	280	50	5	21.0	56.0	10.0	5.4
6	121	36	207	437	140	13	15.9	33.6	10.8	10.7
27	100	37	94	272	116	12	7.8	22.7	9.7	12.0
29	98	33	211	437	130	12	17.6	36.4	10.8	12.3
20	131	35	126	376	185	18	7.0	20.9	10.3	13.7
5	154	28	279	762	256	28	10.0	27.2	9.1	18.2
21	269	26	555	1463	515	50	11.1	29.3	10.3	18.6
24	106	35	194	576	231	21	9.2	27.4	11.0	19.8
16	115	43	329	811	242	23	14.3	25.3	10.5	20.0
18	148	36	308	669	305	30	10.3	22.3	10.2	20.3
23	139	27	236	651	341	30	7.9	21.7	11.4	21.6
14	101	39	240	526	242	22	10.9	23.9	11.0	21.8
31	116	33	220	722	277	26	8.5	27.8	10.7	22.4
9	163	28	532	1310	396	37	14.4	35.4	10.7	22.7
26	173	38	340	938	597	40	8.5	23.5	14.9	23.1
12	104	36	350	792	261	26	13.5	30.5	10.0	25.0
25	92	51	217	423	298	23	9.4	18.4	12.9	25.0
10	110	31	257	420	259	29	8.9	14.5	8.9	26.4
28	114	29	312	770	320	32	9.8	24.1	10.0	28.1
1	95	42	291	784	315	27	10.8	29.0	11.7	28.4
15	152	39	375	979	540	50	7.5	19.6	10.8	32.9
35	92	36	453	899	311	31	14.6	29.0	10.0	33.7
Average per farm										
22 farms, 1922	127	34	283	695	288	27	10.5	25.7	10.7	21.3
23 " 1920	128	32	281	704	236	28	10.0	25.1	8.4	21.9
21 " 1921	129	30	313	744	236	24	13.0	30.8	9.8	18.6
22 " 1923	130	34	276	673	316	31	8.9	21.7	10.2	23.8
23 " 1924	129	33	261	603	218	21	12.4	28.7	10.4	16.3

Miscellaneous crop labor.—The hours of labor used for crops, as considered in the previous discussion and as presented in the appendix, include only direct field work on these crops. They do not include the labor expended in cleaning and treating seed; purchasing seed, twine, and other materials; cleaning and grading market grain, baling hay and straw; or marketing crops. As only a small amount of the crops is sold from these farms, the amount of this type of labor is small. On one farm it was 18 per cent of the total field labor on crops, but the average was only 3.33 per cent of the man labor and 1.25 per cent of the horse work used for field work. Tables XIII and XIV show the amount of this type of work for each farm in 1922 and the average of all farms for each of the five years.

Miscellaneous livestock labor.—The livestock labor presented in the previous sections includes only the direct work on each class of stock—the regular daily care of the stock and such irregular work as buying and selling, caring for sick animals, and other labor directly chargeable to a specific class of stock. In addition to this, considerable time is spent on each farm in grinding feed, hauling feed and bedding, and other operations connected with the maintenance of livestock, but which serve several classes of stock jointly. The amount of this labor, as well as of direct labor on livestock is shown in Tables XIII and XIV, for each farm in 1922 and the average for all farms for each year. The man labor of this type is relatively small as compared with the direct labor. It averages less than 3.5 per cent of the direct man labor. The horse work, however, averages 77 per cent of the direct horse work and on many farms exceeds it.

Maintenance labor.—In addition to the man labor and horse work that may be charged directly to the crop and livestock enterprises, a considerable amount of maintenance or upkeep work is essential which can not be charged directly to any enterprise or group of enterprises. This is classified in five groups and the amount of each is shown in Tables XIII and XIV. Real estate labor consists in repair and upkeep of buildings, fences, drains, water systems, lighting plants, etc., as well as any new construction. Under machinery labor is listed time spent repairing machinery and equipment, purchasing repair materials and purchasing new machinery. General expense labor includes trimming trees, mowing lawns, work on public or farm roads, attending farm organization meetings, office work in connection with the farm business, and any other tasks that serve the entire farm organization but can not be allocated directly or indirectly to any specific enterprise. Household labor includes time spent hauling and preparing fuel, purchasing household supplies, and similar tasks commonly performed by the men on the farm. This does not include any routine household tasks, even tho they may have been

performed by the farmer or his hired help. The labor on garden, orchard, and potatoes includes only time spent in producing food for consumption on the farm.

The relative amount of this maintenance labor varies widely from farm to farm, but the average for all farms is fairly constant. The amount is determined in part by the kind and amount of equipment, the kind and arrangement of buildings, the farm and farmstead layout, and similar physical factors, but also to a large extent by personal factors, such as the managerial ability of the operator, his improvement program, and the relations between the home and the farm business. In planning the labor program of a farm, allowance must be made for this maintenance labor in addition to the crop and livestock labor. However, the amount of this labor does not vary directly with the kinds of crops grown or the classes of livestock maintained and can be largely ignored in studying adjustments in the productive enterprises. This type of work is not usually as fixed in point of time as is the regular crop and livestock work. Much of the repair and upkeep work can be shifted to slack periods during the year or even from one year to another. Permanent improvements, as building construction or tiling, may greatly increase this class of work during a given year and special provision must be made in the labor supply to handle them. The larger percentage of this maintenance labor in 1923 was due to the building of houses on two farms and additions to barns on three others.

Planning the Labor Program of the Farm

A representative distribution of labor for each of the important crops and for each class of livestock has been shown, with a statement as to the usual time of performing each of the operations. In Figure 18 these dates are so combined as to indicate the periods of competition between crops. These the farmer must know if he is to avoid an undesirable piling up of labor at certain periods. It is his problem so to adjust his cropping plan as to reduce these conflicts to a minimum and yet provide as regular and continuous a succession of crop labor throughout the season as is possible.

The crop labor demands are distinctly seasonal and there are frequent periods of competition between crops. The exact date for any given operation may vary from year to year, but the general sequence is the same. Livestock, on the other hand, requires labor throughout the year and in fairly constant quantities for considerable periods of time. For most classes of stock this demand is constant through the year. The competition for labor between different classes of stock is often not so important as the competition for feed, pasture, and building equipment.

TABLE XIII

Distribution of Total Man Labor on Farms, 1922

Farm No.	Crop acres per farm	Animal units per farm	Real estate hrs.	Machinery hrs.	General expense hrs.	Household hrs.	Garden, potatoes, orchard hrs.	Total maintenance hrs.	Livestock		Crops		Total man labor on farm hrs.	Per cent maintenance labor of total
									Chore hrs.	Other hrs.	Field hrs.	Other hrs.		
36	93	28	195	319	220	338	360	1432	2518	75	1123	201	5349	26.8
27	100	37	107	29	20	135	8	299	3956	107	1332	4	5698	5.2
29	98	32	232	117	83	87	43	562	4742	174	1833	19	7330	7.7
35	92	33	189	269	109	275	96	938	4212	139	2172	143	7604	12.3
6	121	44	172	216	475	160	13	1036	4468	406	1592	111	7613	13.4
31	116	38	257	104	77	140	130	708	4586	92	2219	45	7650	9.3
14	101	39	126	35	132	192	130	615	5248	74	1842	35	7814	7.9
24	106	37	279	95	42	74	55	545	5213	147	1978	32	7915	6.9
23	139	37	302	209	49	138	69	767	4742	74	2406	12	8001	9.6
18	148	53	109	47	43	281	98	578	4760	180	2595	39	8152	7.1
12	104	37	169	72	65	154	14	474	5109	138	2361	70	8152	5.8
28	114	33	110	104	57	133	13	417	5341	102	2365	27	8252	5.1
1	95	40	275	112	101	442	141	1071	4973	217	1982	49	8291	12.9
10	110	34	328	57	44	324	87	840	5525	69	2064	20	8518	9.9
5	154	43	673	473	179	146	337	1808	4413	221	2318	97	8857	20.4
25	92	47	457	284	63	52	115	971	5940	219	1734	47	8911	10.9
20	131	46	297	401	249	279	143	1369	6282	211	2014	52	9928	13.8
16	115	49	369	156	154	231	260	1170	5917	145	2689	69	9990	11.7
15	152	59	345	161	130	330	18	984	5481	364	3253	40	10122	9.7
26	173	66	544	232	75	125	41	1017	7038	227	2979	64	11325	8.9
9	163	45	205	263	31	137	364	1000	7293	198	3541	219	12251	8.2
21	269	69	567	192	305	255	142	1461	10237	216	4021	67	16002	9.1
Averages														
22 farms, 1922	127	43	287	179	123	201	122	912	5363	172	2292	66	8805	10.4
23 " 1920	128	41	386	115	98	184	103	886	4792	177	2431	81	8367	10.6
21 " 1921	129	39	344	198	79	214	143	978	5274	171	2257	78	8758	11.2
22 " 1923	130	44	496	155	167	165	174	1157	5172	192	2053	90	8664	13.4
23 " 1924	129	43	259	152	214	173	65	863	4776	162	2317	67	8185	10.5

TABLE XIV

DISTRIBUTION OF TOTAL HORSE WORK ON FARMS, 1922

Farm No.	Crop acres per farm	Animal units per farm	Real estate hrs.	Machinery hrs.	General expense hrs.	Household hrs.	Garden, orchard hrs.	Total maintenance hrs.	Livestock		Crops		Total horse work on farm hrs.	Per cent maintenance work of total
									Chore hrs.	Other hrs.	Field hrs.	Other hrs.		
36	93	28	58	36	68	114	708	984	303	64	4406	244	6001	16.4
27	100	37	77	18	8	94	21	218	106	75	3068	8	3475	6.3
29	98	32	98	..	31	35	28	192	89	207	3221	22	3731	5.1
35	92	33	45	12	40	141	99	337	189	251	4274	61	5112	6.6
6	121	44	100	70	817	178	14	1179	624	352	2786	127	5068	23.3
31	116	38	55	11	50	58	113	287	166	67	4674	29	5223	5.5
14	101	39	23	4	122	61	70	280	136	111	3879	14	4420	6.4
24	106	37	80	4	8	64	44	200	116	108	3955	..	4379	4.6
23	139	37	70	..	18	38	68	194	170	48	4435	..	4847	4.0
18	148	53	43	..	10	128	74	255	354	243	5634	12	6498	3.9
12	104	37	98	4	60	106	23	291	218	204	4968	72	5753	5.1
28	114	33	18	3	10	62	11	104	138	172	4870	10	5294	2.0
1	95	40	44	2	38	207	170	461	230	360	4465	15	5531	8.3
10	110	34	107	2	32	442	39	622	211	86	4636	10	5565	11.2
5	154	43	127	21	49	134	367	698	223	354	3817	38	5130	13.6
25	92	47	50	..	..	52	100	202	200	356	3477	18	4253	4.8
20	131	46	68	106	226	298	44	742	278	159	5324	24	6527	11.4
16	115	49	61	..	20	31	253	365	112	197	5271	77	6022	6.1
15	152	59	62	6	122	113	14	317	298	194	6178	24	7011	4.5
26	173	66	98	8	42	37	58	243	127	170	7631	36	8207	2.9
9	163	45	22	14	52	34	228	350	197	38	8165	118	8868	3.9
21	269	69	49	..	177	217	60	503	330	216	6622	17	7688	6.5
Averages														
22 farms, 1922	127	43	66	15	91	120	118	410	219	183	4807	44	5663	7.2
23 " 1920	128	41	173	18	59	132	74	456	291	229	3980	67	5023	9.1
21 " 1921	129	39	101	20	56	129	100	406	266	169	4408	59	5308	7.6
22 " 1923	130	44	108	17	106	94	195	520	186	241	4451	46	5444	9.6
23 " 1924	129	43	78	14	113	103	49	357	379	205	4674	59	5674	6.3

The main problem in planning the labor program of the farm is so to combine the crop and livestock enterprises that the total labor expended on them, when increased by the necessary miscellaneous labor, will be so distributed throughout the year as to make the fullest and most effective use of available labor.

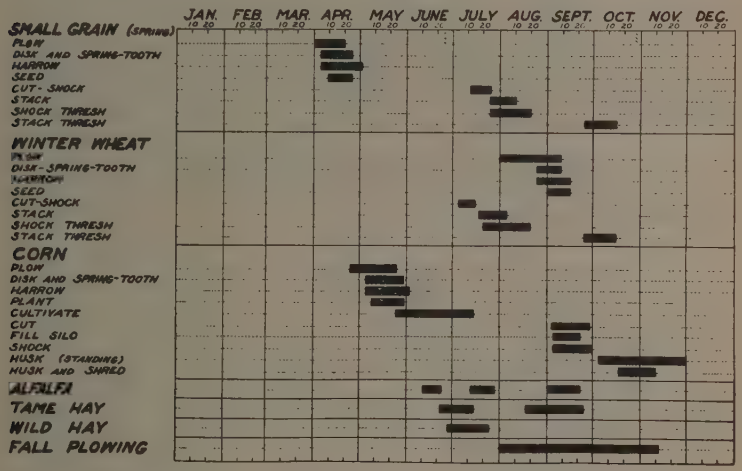


Fig. 18. Usual Period for Performance of Field Crop Operations in Steele County

Different crops use the farmer's labor at different periods during the year. The small grain crops conflict with each other, but interfere little with corn. The hay crops conflict little with each other, but all compete at some period with the corn crop.

Day-to-day management of labor.—In addition to the general problem of so adjusting the crop and livestock enterprises as to secure a desirable seasonal distribution of labor, the farmer must work out the details of his labor program from day to day. Such tasks as feeding and caring for livestock must not only be performed every day, but at certain rather definite times. Many crop operations, such as seeding and harvest, are almost as fixed, but owing to seasonal variations can not be as definitely planned for in advance. Such other work as hauling manure, repairing buildings and fences, and marketing non-perishable products, may be shifted about considerably according to the press of other work.

Weather must also be considered in laying out the tasks for a particular day. Some work can be done when it is raining, other work when the ground is wet but rain is not actually falling. Other work requires freedom from both rain and wet soil. Likewise, some tasks can be performed only when the ground is thawed, others when the ground is frozen but free from snow, and still others when the ground is both frozen and covered with snow. In the day-to-day management of labor the farmer should give tasks preference according

to their time fixity and their relation to weather conditions.[3] Work that can be shifted about should be used to fill the gaps between tasks whose time of performance is relatively fixed. The actual working out of this on a 208-acre farm is shown in Figure 19. This represents a desirable adjustment of fixed and shifting labor. Under "fixed labor" are included livestock feeding and care and field crop work which must be done at a specific time or can vary only within narrow limits. In "shifting labor" are included all tasks that can be shifted freely within seasonable limits or even throughout the year. Most of the shifting labor is performed during the winter. Shifting work during the crop season is done largely on rainy days or between the important crop operations. In this way the labor distribution is fairly uniform throughout the year.

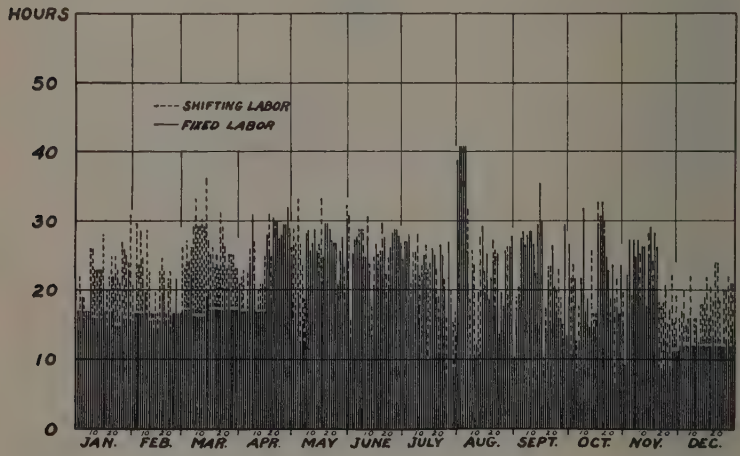


Fig. 19. Day-to-day Adjustment of Fixed and Shifting Labor on a 208-Acre Farm

Seasonal tasks should be performed when conditions are most favorable. Other work that can be done at any time should not be allowed to interfere with them, but may be fitted in at slack periods so as to secure a fairly uniform distribution of labor for the year.

Exchange labor.—Such operations as threshing and silo filling require large amounts of labor for from one to four days. Even the most careful adjustment of enterprises and the best balanced day-to-day planning can not obviate these peak loads. To hire this extra labor would be expensive. Often it is not available. The customary method of meeting these peak demands in this area is through exchange labor between farms, as illustrated in Figure 20. There were four periods during which the regular labor supply was inadequate to meet

[3] For a fuller discussion of this point see Minn. Agr. Exp. Sta. Bul. 205.

the peak demands—threshing in August, silo filling in September, flax threshing in October, and corn shredding in November. By means of exchange labor the peak load of these 8 days was spread over 40 days and thus was handled with the regular force.

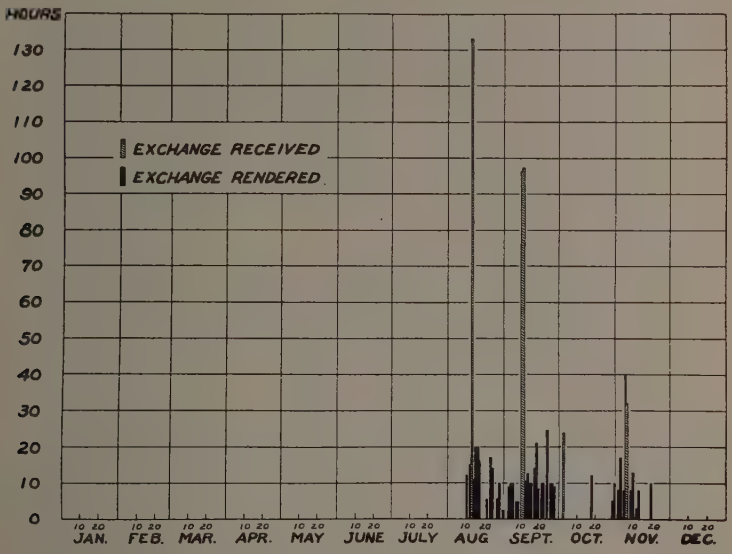


Fig. 20. Exchange Labor on a 220-Acre Farm

By exchanging labor with their neighbors, farmers are able to avoid hiring extra help for threshing, silo filling, and other tasks demanding large amounts of labor for short periods.

Tractor Work

Tractors are used on more than half the farms studied, but are seldom used exclusively for any one operation. In presenting the amounts of labor used for various crop operations, both horse and tractor work are reported for the same operation on farms where tractors are used. The average in most cases includes some tractor work. The common practice of using both tractor and horses in the same field and for the same operation makes it impossible to compute separate rates, and difficult to study the range of labor expenditures between farms, particularly as the size of tractor varies as well as the extent of its use. The standards presented are all computed in terms of horse work. If these are to be applied on farms where tractors are used, allowance must be made for any saving in man labor as well as for the substitution of tractor for horse work.

TABLE XV

AMOUNT AND KIND OF TRACTOR WORK DONE, 1920

Farm No.	Size of tractor	Crop acres	Drawbar					Belt				Custom			Total tractor work hrs.
			Plowing hrs.	Seedbed preparation hrs.	Cutting grain hrs.	Miscellaneous hrs.	Total hrs.	Grinding feed hrs.	Sawing wood hrs.	Silo filling, threshing, shedding hrs.	Total hrs.	Drawbar hrs.	Belt hrs.	Total hrs.	
35	3-plow	91	85	32	..	12	129	..	..	24	24	4	..	4	157
31	2-plow	117	138	43	..	10	191	20	9	41	70	..	15	15	276
3	2-plow	113	166	88	..	..	254	..	..	18	18	..	14	14	286
28	3-plow	115	168	32	..	..	200	..	..	53	53	..	64	64	317
12	3-plow	97	148	101	..	..	249	..	8	46	54	..	38	38	341
*	3-plow	219	208	38	18	7	271	60	14	15	89	..	10	10	370
32	2-plow	164	164	51	..	6	221	33	2	142	177	..	..	..	398
6	2-plow	120	141	151	..	..	292	51	..	24	75	..	43	43	410
5	4-plow	182	102	97	110	13	322	..	6	59	65	..	28	28	415
15	3-plow	152	193	100	..	12	305	38	23	22	83	22	36	58	446
37	2-plow	224	137	24	35	..	196	12	..	38	50	173	33	206	452
33	2-plow	128	241	108	..	9	358	39	16	47	102	..	..	..	460
21	3-plow	253	194	144	52	16	406	46	..	42	88	..	..	..	494
9	2-plow	172	324	163	83	96	666	88	19	51	158	..	10	10	834
Averages															
14 tractors,	1920.....	153	172	84	21	13	290	28	7	44	79	15	20	35	404
12† "	1921.....	159	119	48	16	6	189	40	4	50	94	1	7	8	291
12† "	1922.....	133	105	41	4	11	161	27	3	36	66	..	13	13	240
11‡ "	1923.....	146	75	41	8	12	136	30	2	38	70	..	23	23	229
11§ "	1924.....	136	63	30	7	6	106	42	6	31	79	..	44	44	229

* Owned and used co-operatively by two farmers.

† Includes three 2-plow, eight 3-plow, and one 4-plow tractors.

‡ Includes three 2-plow, seven 3-plow, and one 4-plow tractors.

§ Includes two 2-plow, eight 3-plow, and one 4-plow tractors.

Some idea of the extent of tractor use and the kind of work done is presented in Table XV. Data for each farm for 1920 are given and averages for the succeeding years. The year 1920 was selected because of the larger use of tractors that year. High prices for horse feeds as compared to prices for tractor fuel are an important factor in causing the large use of tractors in 1920. As feed prices declined, tractor use fell off sharply. The use of the tractor for field operations as a substitute for horses also steadily declined. The amount of belt work remained fairly constant and the custom work tended to increase. Considerable employment is provided for tractors by feed grinding, silo filling, and corn shredding, even tho they are not used for field operations.

PART III. APPLICATION OF UNIT EXPENDITURE AND LABOR DISTRIBUTION DATA TO ORGANIZATION OF FARM BUSINESS

Principles of Choice and Adjustment of Enterprises Affecting Factors

The basic data presented thus far are useful in planning a farm organization that will more effecively utilize the resources within the farmer's control. Before illustrating the methods of their use, some attention should be given to the general principles of choice and adjustment of enterprises.

In deciding the kind and acreage of crops to be grown and the kind and numbers of livestock to be maintained, the following general considerations must be kept in mind:

1. The adaptation of the enterprise to conditions in the area.
2. The varying demands of the several enterprises on the resources of the farmer.
3. The inter-relations between enterprises.
4. The possibilities for utilizing relatively fixed resources in the farmer's possession.
5. The facility with which enterprises lend themselves to shifts.
6. Changes in prices of products or in prices of cost factors.

Area Adaptation of Enterprises

In such an old settled area as Steele County, the adaptation of the various crops has been well worked out and only those adapted to the region are retained. The history and development of cropping systems have been discussed in Part I. The principal problems of this kind that may arise in Steele County concern new varieties of crops developed or new species introduced. Minturki wheat (winter) is a new variety

introduced during the period of this study that apparently has demonstrated its adaptability and yielding power. Alfalfa is a new species that has become established during the same period.

Disease and insect problems also may arise which affect the quality as well as the quantity and certainty of yields. However, there are at present no problems of this type affecting any of the important crops produced in this area. Marketing facilities are also a factor in area adaptation but, as has been pointed out, Steele County has adequate marketing facilities.

Variations in Use of Farmer's Resources by Different Enterprises

It has been noted that widely differing amounts of labor are used by the various crops and livestock and that the seasonal distribution varies widely. Small grain requires large amounts of labor for relatively short periods at seed time and harvest. Corn, on the other hand, requires more labor per acre, but over a much longer time. Small grains require attention at about the same time, but corn and small grain conflict very little with each other. Alfalfa and tame hay conflict little but both compete with corn at certain seasons. Labor requirements on livestock are continuous and fairly constant throughout the year and compete with crops for labor throughout the season. The amount of labor required by different classes of stock varies greatly, dairy cows requiring large amounts of labor continuously throughout the year, and hogs comparatively little.

All crops compete with each other for land. Crops use relatively large amounts of machinery and equipment, whereas livestock, particularly dairy cows, require relatively more outlay for shelter. Different classes of livestock need different kinds of feeds as well as different amounts. Cattle, sheep, and horses use considerable quantities of pasture and roughage, while swine and poultry use little but concentrates. All these peculiarities must be considered and given due weight in planning a well-balanced farm organization.

Enterprise Inter-relations

Enterprises compete with each other for the use of the farmer's resources, as has been pointed out. They also complement and supplement each other. Two enterprises are said to be complementary when one contributes to the production of the other. Feeding crops and livestock are complementary in that the crops contribute feed to the stock and the stock contribute manure to stimulate crop production. By-products of one enterprise can be used advantageously by the other. The skimmilk produced by the dairy herd is a valuable protein supplement for swine and poultry. This use of the non-marketable by-

products of one enterprise by another is a common inter-enterprise relation in farming and is an important factor in determining enterprise combinations.

An enterprise is said to be supplementary to another when it enables the farmer to make fuller utilization of the labor, horse power, equipment, land, and other resources used in the production of the other enterprise. The farmer who raises only wheat is very busy for short periods of time, but has little to do the rest of the year. The addition of corn to the cropping system will furnish steadier employment for the farmer and his horses and more use for his equipment.

Certain enterprises may be directly competing at certain times of the year and not compete at other times. They may be both complementary and supplementary. These inter-relations can not be definitely stated or accurately measured. They introduce some very complex difficulties in farm enterprise accounting. They must, however, be recognized and reckoned with in combining and adjusting enterprises.

Utilizing the Farmer's Fixed Resources

The labor force of the farm, so far as it consists of the farmer and his family, is a more or less fixed resource. An enterprise or combination of enterprises that will furnish this labor supply the fullest employment consistent with their personal well being is likely to produce the largest net farm income, even tho the return from some is low. A low return is better than none. The same principle holds with regard to buildings. It may not pay to erect a barn to shelter a certain class of stock, but once the barn is erected the farmer may find it profitable to raise this class of stock as long as they can pay rent for its use over the current upkeep cost due to use. Many farm investments of this type can not be readily converted to other uses. For a given farm they are important factors in determining the line of production.

Facility with Which Enterprises Lend Themselves to Shifts

There is a wide variety in the fixity, as well as in the amount, of investment required for different enterprises and also in the time required to establish the enterprise. Most crops have an annual cycle. The farmer may plant all his small grain land to wheat one year and then shift to oats or barley the following year with no material change in investment. Except where large amounts of special equipment are needed, shifts between the annual crops are generally made rather easily. The production cycle in livestock, however, is much longer and shifts are much more likely to involve loss, particularly with breeding stock. It takes years to develop a high producing dairy herd and constant care in breeding and weeding to maintain it. It takes approximately three years from the time a cow is bred until her offspring can be added to

the producing herd. Perhaps only half the calves will be heifers and, these must be culled if quality is to be maintained. This long cycle of production and slow rate of increase is an important factor in the stability of the dairy business, especially in such an area as Steele County, where the farmers raise their own stock and considerable attention is being paid to purebred stock. In beef cattle the rate of turnover is also slow, except in feeding purchased cattle. Swine and poultry, on the other hand, increase rapidly and shifts can be made quickly, except as shelter and equipment are limiting factors. Because of the complementary relation of dairy cows and swine, the swine enterprise tends to be relatively more stable on dairy farms than on others.

Livestock farming involves the seeding down of meadows and pastures. This introduces a longer cycle into crop production and to that extent tends to stabilize the cropping system.

Price Changes

The returns from any farm organization will vary from year to year, because of changes in prices of the cost factors and in prices of farm products. An organization profitable in one year may be decidedly less profitable the next. Prices of farm products vary seasonally and from year to year, and in many cases in fairly definite cycles over periods of several years. In so far as seasonal price variations are fairly constant, marketing may be adjusted to take advantage of them. Changes from year to year, especially in crop prices, may be due to variations in production caused by seasonal conditions. These can hardly be anticipated. Many of the cyclical changes are so regular in extent and duration that the farmer who has the best information available regarding these cycles may make adjustments to take advantage of the changes.

In addition to these periodic fluctuations in prices, in which changes up and down may roughly balance, there may be certain more or less permanent economic changes that may cause a definite trend either upward or downward. The competition of new wheat land in Canada and Argentina may tend to depress the price of wheat for some years. Cheap corn and beef from Argentina may likewise affect the domestic price for these commodities. On the other hand, insects or diseases that affect large competing areas, or added tariff, may so stimulate prices as to insure higher levels for some time in the future.

The policies of farmers in organizing their business to meet changing price conditions vary between two rather wide extremes. Farmers at one extreme have attempted to shift their production with shifting prices. Occasionally a man of unusual foresight and judgment may do this successfully, but the average farmer usually shifts just too

late. He plans next year's acreage in line with this year's price, with the result that if enough other farmers do the same thing price conditions are likely to be reversed. Other farmers go to the other extreme of planning out a definite system of crop and livestock production and follow it fairly rigidly from year to year without much regard to price changes. Probably the safest policy for most farmers to follow would be a modification of the latter plan to allow greater elasticity in the choice and adjustment of enterprises.

At the present time public and private agencies are making extensive studies of the factors that affect prices. The United States Department of Agriculture and the various agricultural experiment stations are making available much information regarding price cycles, conditions of supply and demand, and probable future price and production trends. A plan of farm organization sufficiently elastic to allow some shifting with permanently changed price conditions, as well as with cyclical price changes, so far as the use of the farmers' fixed resources permit these changes, will probably be the most satisfactory from the standpoint of stability of return. The farmer who makes fullest use of all available information regarding price and production trends will be able to keep his farm organization most accurately adjusted to changing price conditions.

Conditions Affecting the Application of Farm Organization Principles to a Specific Farm

That the farmer is dominated by economic motives—that he is seeking the largest possible net return from his business—is assumed in most studies of this nature. It must always be recognized, however, that personal considerations may outweigh the desire for profit, and farmers often forego maximum returns rather than make changes in their organization that affect unfavorably the home and family life or that introduce enterprises or operations that are personally distasteful. It is therefore the purpose of this analysis merely to point out methods by which the farmer may forecast the increase in his net income that will result from specific adjustments in his farm organization. It then remains for him to decide whether this increase is sufficiently large to outweigh any personal objections or inertia that oppose the change.

There are two general types of changes in the farm organization that will affect the farm income. The first includes changes in the kinds or acreage of crops grown and in the kinds and number of livestock maintained. This is sometimes termed the problem of choice and combination of enterprises or of external enterprise relations. The second type deals with methods and practices within a given enterprise. It concerns cultural practices, feeding systems, and husbandry methods. It deals with internal enterprise adjustments and may be termed a study of enterprise efficiency.

In building up a new farm organization or developing a system of farming in a newly settled country, the problems of the first type are by far the more important. They may be relatively more important in crop farming than in livestock production. However, in an old settled county with a comparatively well settled type of farming fairly uniformly followed, as in Steele County, it is probable that enterprise relations have been fairly well worked out. Maladjustments of enterprises are not likely to be especially numerous or serious. On the other hand, the wide range in the amount of labor and materials used indicates a wide range in efficiency in the conduct of specific enterprises. The possibility of increasing the net income of these farms through a realignment of enterprises is undoubtedly much less than through the adoption of improved husbandry practices within the enterprises. The latter may of course involve some changes in the choice and relative size of enterprises; for example, the most profitable dairy production may necessitate an increase in the alfalfa acreage, or the addition of rape or alfalfa pasture may result in economies in swine production. The data that have been presented in this publication are useful in studying both types of problems.

In applying these data it should be remembered that several factors can not easily be measured. Perhaps the most important of these is the managerial ability of the farm operator. In suggesting changes it is assumed that the farmer's efficiency as a producer would remain the same—that he would handle new enterprises or increased enterprises as effectively as he does those he is now conducting. It is entirely possible that increases or decreases in efficiency may result from the proposed changes. This it is impossible to determine. It is believed that this assumption of constant efficiency, except for very radical changes in the farm organization, involves no material error that would seriously detract from the value of the analysis based upon it.

It should be observed that in a fairly uniform and fixed system of farming such as the dairy type in Steele county, the farm business is built up around one or more major enterprises. In this case the dairy is the central enterprise. Next in importance and closely associated with it is the swine enterprise. The cropping system is designed largely to furnish the greatest amount of feed of the kind that these two classes of livestock can use most effectively. Occasionally the feed crops are supplemented by some crop grown for sale, but the feed crops dominate the cropping system.

Use of Unit Expenditure Data in Forecasting Effect of Enterprise Adjustments

General Plan of Application

The following examples will illustrate the use of data presented in Part II in forecasting the effect of specific adjustments on the net return. The general plan used is a method of substitution, or alternatives. The analysis is based on the assumption that in studying enterprise adjustments only the costs and return that will be directly affected need be considered. Such changes as will be proposed do not ordinarily affect overhead costs, land rent, and other fixed charges, at least not materially.

Illustration No. 1. Resources and Present Productive Organzation

The following is a description of the resources and productive organization of a farm as it existed in 1922. Normal crop yields for the locality have been substituted for actual in order to avoid the effect of seasonal variations upon the amount available for feed and sale. Actual livestock production is used. The distribution of the total farm acreage and the normal yield of each crop are given in Table XVI.

TABLE XVI
DISTRIBUTION OF ACREAGE AND PRODUCTION OF CROPS (PRESENT ORGANIZATION)

Real estate and crops	Acres	Yield per acre	Total production
Corn for grain, bu.	33.0	45	1485
Corn for silage, tons	22.5	6½	146
Corn for fodder, tons	3.5	2½	9
Oats, bu.	15.5	45	700
Oats and barley, bu.	45.0	40	1800
Rye, bu.	7.0	15	105
Tame hay, tons	46.0	1¾	81
Wild hay, tons	7.0	1¼	9
Total crop area, acres	179.5		
Pasture (permanent) acres	92.5		
Farmstead and waste, acres	8.0		
Total farm area, acres	280.0		

The buildings were sufficient to take care of 30 cows, 35 young cattle, 15 brood sows and their pigs, and 200 chickens.

The livestock maintained and its production are shown in Table XVII.

TABLE XVII
NUMBER AND PRODUCTION OF PRODUCTIVE LIVESTOCK (PRESENT ORGANIZATION)

Kind of livestock	No. of head	Production
Cows	26	4200 lbs. butterfat
Other cattle	32	
Brood sows	7	17000 lbs. pork
Chickens	75	

The labor supply and the power and equipment utilized under the existing plan of operation are given in Table XVIII.

TABLE XVIII

LABOR, POWER, AND EQUIPMENT SUPPLY (PRESENT ORGANIZATION)

A. Man Labor
Operator for the entire year.
One hired man for the entire year.
One hired man April 1 to December 1.
Operator's wife, who assisted with dairy utensils.
Extra help as needed.

B. Power
Twelve work horses throughout the year.[4]
A 12-20 tractor, used only for belt work.

C. Machinery
The farm was fully equipped for the crops grown or proposed.

The distribution of labor on this farm is shown in Figure 21. Only the labor actually performed is included. It does not represent the exact labor accomplished by the farmer and his regular labor supply because exchange labor received is included and that rendered is not. The regular supply of labor, computed on the basis of a normal day's work for each regular worker, is also shown. At practically all times the labor used exceeds the regular supply. The deficit is largely made up by hiring extra help irregularly. To a limited extent the regular workers lengthen their normal working day. Exchange labor is also used to take care of peak loads. In August, when the labor used was less than the supply, much time was spent by the regular workers on exchange work for neighbors. A similar comparison of horse work supply and utilization is not necessary, as the supply at all times exceeded the amount used.

The following prices are used in the computations of cost and income on this farm: wheat $1.20 per bushel; butterfat 50 cents per pound; pork 8 cents per pound. They represent, as nearly as can be estimated, a normal relation between prices. In making such a computation the farmer should have the best information available regarding the probable trend of prices.

The labor rates for crops which will be affected by the adjustments proposed are shown in Table XIX. The material costs for crops are given in Table XX. These are the actual rates on this farm and may be considered normal.

[4] Besides supplying power, the work horses produce several colts annually. Six unbroken colts are kept.

TABLE XIX

HOURS OF LABOR PER ACRE FOR CROP PRODUCTION

	Man	Horse		Man	Horse
Wheat and rye			Corn		
Plowing	2.0	12.0	Plowing	2.1	11.4
Seedbed preparation	1.7	6.5	Seedbed preparation	3.6	14.1
Seeding	0.7	2.6	Planting	0.7	1.4
Cutting	0.8	3.2	Cultivating	7.6	15.2
Shocking	2.0		Husking	8.4	16.8
Stacking	3.3	4.8	Alfalfa		
Threshing	1.9	1.2	1st cutting	5.5	10.5
Marketing	1.0	2.0	2nd cutting	5.0	9.5
Tame hay, 1st cutting	5.2	10.4	3rd cutting	4.5	9.0

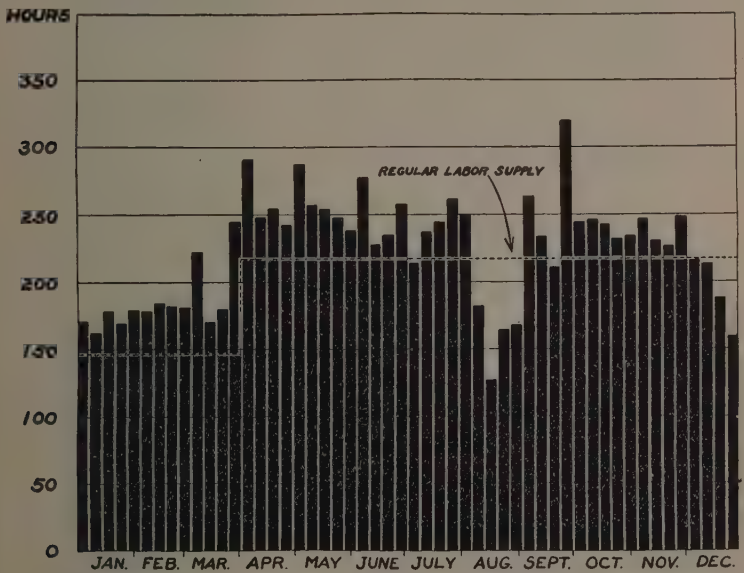


Fig. 21. Distribution of Labor by Weeks and Regular Supply of Labor (Present Organization)

The labor needed on this farm as now operated exceeds the regular supply by a wide margin. Irregular day labor used to fill in is not as dependable and usually is more expensive than regular workers hired by the season or year.

TABLE XX

MATERIAL COSTS FOR CROPS

	Seed per acre	Twine per acre	Threshing per bu.
	lbs.	lbs.	cents
Corn for grain	8	..	..
for fodder or silage	16	4	..
Oats	80	3½	3.5
Oats and barley	80	3½	3.5
Rye	84	2½	6.0
Winter wheat	90	3	6.0
Clover	8	..	..
Timothy	4	..	..
Alfalfa	12	..	..

The actual feeds and labor used for livestock production are shown in Table XXI.

TABLE XXI
AMOUNTS OF FEED AND LABOR USED FOR LIVESTOCK

	Corn	Small grain	Hay	Silage	Corn fodder	Skim-milk and butter-milk	Vet. services and medicine	Man labor	Horse work
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.		hrs.	hrs.
Per work horse	1750	1325	3250				$0.80	75.0	..
Per colt	400	350	520				...	*	..
Per cow	400	1575	2900	7500	375		0.30	150.0	5.0
Per head young cattle	50	175	1900	3000	250	1900	...	42.0	..
Per 100 lbs. pork	260	160		...		500	...	4.2	0.5
Per 100 chickens	250	2100					...	144.0	..

* Included with work horses.

The crops raised on this farm are all fed to livestock. The disposal of the several crops is shown in Table XXII.

TABLE XXII
DISPOSITION OF CROPS PRODUCED

	Total production	Seed	Net production	Amount fed
	lbs.	lbs.	lbs.	lbs.
Corn for grain	83,160	680	82,480	79,800
for silage	292,000		292,000	291,000
for fodder	18,000		18,000	17,750
Oats	22,400	1240	21,160	21,000
Oats and barley	72,000	3600	68,400	67,000
Rye	5,880	588	5,292	5,200
Hay	180,000		180,000	178,320

Not all of some crops is needed for feed. In actual practice the balances would be large in years of high yields and disappear in years of low yields. Usually it is well to have some surplus in a normal year in order not to be too short when yields are low. This surplus may be sold or some temporary expansion of the livestock enterprises may be made to take care of it.

An earning statement of the farm under the present organization is presented in Table XXIII.

TABLE XXIII

FINANCIAL RETURNS FROM PRESENT ORGANIZATION

Sales			
Butterfat, 4200 lbs. at 50 cents	$2100		
Cows	300		
Veal calves and heifers	500		
Pork, 17,000 lbs. at 8 cents	1360		
Poultry and eggs	100		
Total sales			$4360
Cash Crop Costs:			
Seed (timothy and clover)	55		
Twine (small grain)	28		
Twine (corn)	13		
Threshing	94		
Direct cash crop costs		$190	
Cash Livestock Costs:			
Horses (shoeing and medicine)	9		
Cows (veterinary costs)	8		
Salt	9		
Swine (2400 gal. buttermilk)	50		
Direct cash livestock costs		76	
Hired Labor		1375	
Total cash cost of extra labor and materials			1641
Returns to organization after deducting cost of extra labor and materials			$2719

Weaknesses of Present Organization

As this farm is now organized, the labor demand of the enterprises is too heavy during most of the year to be supplied by three men and yet is hardly sufficient to provide regular employment for four. An increase in intensity of production is therefore suggested that will result in a better adjustment of labor supply to demand. Such a change should make a fuller utilization of the available horse labor. Another weak spot in the present organization is the low production of the dairy herd. The cows are well bred and are fed liberally. The ration, however, is low in protein. The tame hay fed contains a large percentage of timothy and the grain ration includes no high protein concentrates. Some high protein feed should be introduced into the ration. All the rye produced is being fed to the hogs. It is not a very satisfactory feed for swine, especially when fed in large quantities. For the community studied, it is not highly profitable as a cash sale crop—can

not compete with winter wheat. Therefore it is recommended that a more suitable crop be selected for the acreage now in rye. Other defects in the present organization could be cited. As the purpose of the proposed changes is to illustrate methods of using the data presented in Part II rather than to correct all the defects, no other faults need to be pointed out.

Reorganization Plan No. 1. Readjusting to Improve the Quality of Feed and to Provide a Cash Sale Crop

To correct the protein deficiency of the dairy ration, it is suggested that tame hay be replaced with alfalfa. As alfalfa yields about twice as much as timothy and clover, only half as large an acreage will be needed to provide the same quantity of hay. The rest of the tame hay land will be seeded to winter wheat. The rye will also be replaced with winter wheat. The winter wheat will add to the cash income. Table XXIV shows the cropping system with the proposed changes.

TABLE XXIV
PROPOSED CROPPING SYSTEM (REORGANIZATION PLAN NO. 1)

	Acres	Yield per acre	Total yield	Amount for seed	Amount for feed	Amount for sale
Corn for grain, bu.	33.0	45	1485	12	1425	...
for silage, tons	22.5	6½	146	..	146	...
for fodder, tons	3.5	2½	9	..	9	...
Oats, bu.	15.5	45	700	39	656	...
Oats and barley, bu.	45.0	40	1800	90	1675	...
Wheat, bu.	30.0	20	600	45		555
Alfalfa, tons	23.0	3½	81	..	80	...
Wild hay, tons	7.0	1¼	9	..	9	...
Total crop area, acres	179.5					
Pasture (permanent), acres	92.5					
Farmstead and waste, acres	8.0					
Total farm area, acres	280.0					

No change in the number of livestock is considered, except that pork production will be curtailed slightly, as the feed for hogs is reduced by the amount of rye eliminated. It is, however, assumed that the substitution of alfalfa for timothy and clover hay will provide a greater supply of protein for the dairy ration and hence increase dairy production 10 per cent. Where a similar substitution has been made on other farms included in this study, much larger percentage increases have resulted, hence the estimate is conservative. This reorganization has another advantage—the introduction of wheat as a cash crop adds an element of diversity to the income of the farm organization and should tend to stabilize the earnings. The increase in earnings under the new plan is given in Table XXV.

TABLE XXV

FINANCIAL STATEMENT OF REORGANIZATION PLAN NO. 1

Crop Sales:			
550 bu. wheat @ $1.20		$660	
Livestock and Livestock Products Sales:			
Butterfat, 4620 lbs. @ 50c per lb.	$2310		
Cows	300		
Veal calves and heifers	500		
Pork, 15,750 lbs. @ 8c	1260		
Poultry and eggs	100		
Total livestock sales		4470	
Total crop and livestock sales			$5130
Cash Crop Costs:			
Seed, alfalfa	32		
Twine, small grain	36		
Twine, corn	13		
Threshing	124		
Direct cash crop costs		205	
Cash Livestock Costs:			
Same as present organization		76	
Hired labor		1525	
Total costs of extra labor and materials			1806
Returns to organization after deducting cost of extra labor and materials			$3324
Net increase over present plan of operation			$ 605

The new plan of operation does not involve any change in buildings, equipment, or livestock investment. The only additional cash outlay necessary has been provided for in the estimates of expense. The net income of the farm is increased $605. This new plan adds 530 hours of man labor and 1120 hours of horse work. The 12 horses now maintained can easily carry the additional load, but the extra man labor must be hired. A comparison between the labor distribution of the present plan and that of the proposed plan is shown in Figure 22. The new plan offers little advantage. Only during the last two weeks in June and the first week in July the labor was lower than at present. At other times it is the same or greater. The second cutting of alfalfa and the stacking of small grain combine to make a heavy peak load about the first of August. The third cutting combines with wheat seeding to make another peak the first week in September. Both these peak loads might be better distributed by exchanging labor with neighbors. The peak during stacking might be avoided by a combination of shock threshing and exchange work. This increased labor load has been allowed for in cash expense.

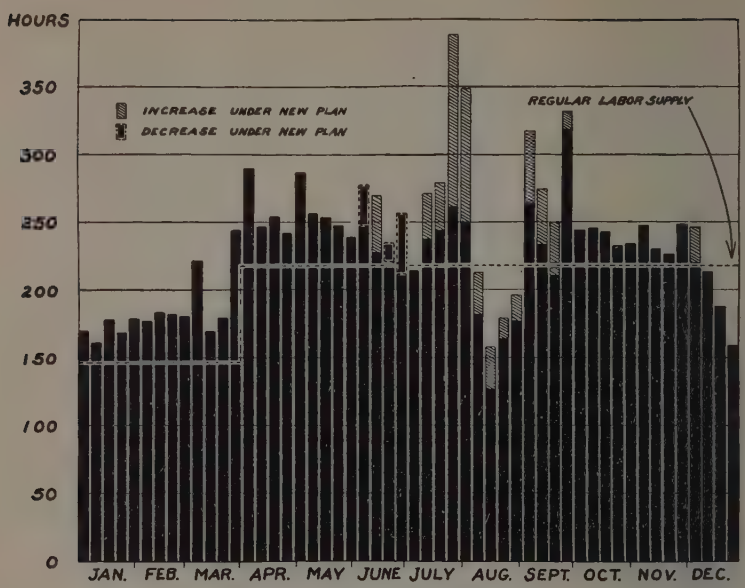


Fig. 22. Comparison of Distribution of Labor by Weeks of Present Plan and First Proposed Plan with Regular Labor Supply

The proposed plan presents a labor distribution no better than the present. Alfalfa seeding conflicts with harvest in July and with wheat seeding in September. More irregular day labor must be hired than before.

Reorganization Plan No. 2. Readjusting to Utilize Labor and Maintain Fertility

The first plan suggested provides a substantial increase in the net income of the farmer. It does not, however, remedy the irregular distribution of labor. There may also be some question as to maintaining the fertility of the soil with the small acreage of legumes and the selling of a considerable quantity of wheat each year. A second alternative is therefore proposed, which will to a large extent avoid these defects. The cropping system in plan No. 2 is the same as in plan No. 1 except that winter wheat is replaced with corn. This is fed to hogs, increasing the pork production from 17,000 to 32,000 pounds. This larger pork production provides a more advantageous utilization of skimmilk. Instead of 500 pounds per 100 pounds of pork produced, about 285 pounds will be available. The grain requirement for producing 100 pounds of pork is increased about 20 pounds to offset the decreased amount of skimmilk. Altho pork production is increased nearly 90 per cent, the increase in labor is estimated at 60 per cent. This estimate is very conservative as compared with actual records on

farms where the swine enterprise was materially increased. It is assumed that the other livestock remain the same and receive the same feed as in Plan No. 1.

TABLE XXVI

REORANIZED CROPPING SYSTEM (REORGANIZATION PLAN NO. 2)

	Acres	Yield per acre	Total yield	Amount for seed	Amount for feed	Amount for sale
Corn for grain, bu.	63.0	45	2835	12	2823	...
for silage, tons	22.5	6½	146	..	146	...
for fodder, tons	3.5	2½	9	..	9	...
Oats, bu.	15.5	45	700	39	656	...
Oats and barley, bu.	45.0	40	1800	90	1675	...
Alfalfa, tons	23.0	3½	81	..	80	...
Wild hay, tons	7.0	1¼	9	..	9	...
Total crop	179.5					
Pasture (permanent)	92.5					
Farmstead and waste	8.0					
Total farm area	280.0					

TABLE XXVII

FINANCIAL STATEMENT OF REORGANIZATION PLAN NO. 2

Sales:			
Butterfat, 4620 lbs. at 50 cents per lb.	$2310		
Cows	300		
Veal calves and heifers	500		
Pork, 32,000 lbs. at 8 cents per lb.	$2560		
Poultry and eggs	100		
Total sales			$5770
Crop Cost:			
Seed, alfalfa	$ 32		
Twine (corn)	13		
Twine (small grain)	25		
Threshing	88		
Direct cash crop costs		$158	
Cash Livestock Costs:			
Same as present organization		76	
Hired labor		1680	
Total cost of extra labor and materials			1914
Returns to organization after deducting cost of extra labor and materials			$3856
Net increase over present plan of operation			$1137

The distribution of labor under this plan is indicated in Figure 23. Enough labor is added that two hired men would be needed throughout the year and an extra man from April 1 to December 1. By employing these men for the year or the season, the labor cost would be less than

if day labor must be hired during rush seasons. There are only a few weeks during the year when this supply would not be adequate. These could easily be handled by exchange work or by the present labor force working more hours per day. Only the labor actually used on this farm is shown. Exchange labor received is included, that rendered is not. The decrease in labor in August does not represent a lull in farm work. During this period one or two men are doing exchange work. Through this exchanging of services the labor performed by the farm workers is kept at a fairly constant level. There is some margin between labor supply and demand throughout the year. This margin of safety provides a desirable element of elasticity in the business. It is, however, entirely possible that the labor demands of the farm could be adequately met and the labor cost reduced by employing a boy in place of one hired man. By assigning to him the lighter tasks, it would still be possible to operate this plan.

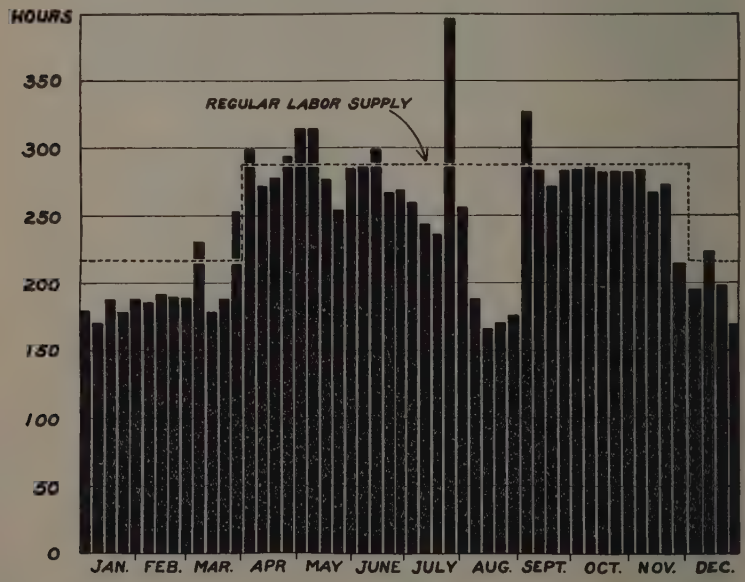


Fig. 23. Distribution of Labor by Weeks and Regular Supply (Reorganization Plan No. 2)

By increasing the corn acreage and the pork production, the productive labor is increased to the point where the hiring of an extra man is justified. Under this plan the labor can all be provided by men hired by the season or year and no day laborers are needed.

The plan provides a very substantial increase in the net income of the farm. It calls for no buildings or equipment not now on the farm. The swine breeding herd would be approximately doubled, but pigs are raised on the farm, so no direct cash outlay is involved. Some labor could be saved by substituting a two-row cultivator for two of

the three one-row cultivators now on the farm. Some labor is also saved by the plan of hogging-off 7 acres of corn instead of only 2¼, as is now practiced. Two litters of pigs will be raised as at present. The cattle sold under both plans are veal calves, surplus heifers, and cows culled out of the herd. It is assumed that these remain the same, altho the substitution of alfalfa for clover and timothy will probably result in better growth of heifers, which may increase their sale value. Soil fertility should be maintained under this system, as butterfat and pork are practically the only products sold off the farm. Provision has been made for labor for hauling out the additional manure produced by the enlarged swine enterprise. This system of operation provides for a fuller utilization of the work horses, equipment, and buildings, all of which are adequate. This plan would call for 1210 more hours of man labor than are now being used, but provision has been made for this in the allowance for wages.

Other changes might be suggested that would further increase the net income. Labor rates for crops are rather high. By using larger equipment and power units these could be reduced. Possibly the tractor could be used to advantage for field operations instead of for belt work only, thus enabling the farmer to sell several work horses. In fact, 12 horses are more than should be required on 179½ acres of crop land even without a tractor. A more careful planning of the labor should increase returns by reducing the number of horses maintained. The dairy production is low in proportion to the amount of feed used. The use of alfalfa hay will help some, but there is need for better stock that will result from more careful breeding and culling. It is not the purpose of this study to suggest remedies for all the defects in the organization of the farms used as examples. The purpose is rather to illustrate the method used in applying the data presented and the principles mentioned in forecasting the results of specific changes.

Effect of Variations in Yield of Crops on Relative Returns from Different Plans

Changes in yields of crops from year to year would not materially affect the relative returns from the two plans suggested as compared with the present plan, as it would affect all in the same way. Should the yield of wheat drop to 10 bushels per acre, other crops remaining the same, the advantage of the first reorganization plan would fall from $605 to only a little more than $270. On the other hand, with a 35-bushel yield, as in 1924, the increase in income would be approximately $1100 instead of $600. A dry season would affect the hay yields less than at present, as alfalfa is more drouth resistant than timothy and clover.

Effect of Price Change on Relative Returns from Different Plans

A decrease in the price of wheat from $1.20 to 90 cents per bushel would decrease the advantage of Plan No. 1 over the present plan from $605 to $440, providing there were no changes in the other cost factors. An increase in price to $1.60 per bushel, on the other hand, increases the added return to $825. In Plan No. 2 the added return would be decreased $240 by a decline in pork prices to 6½ cents per pound, and increased $320 by a rise to 10 cents. In either plan there seems to be an advantage in net return over the present organization, even with a material decline in prices. A radical change in price of products would probably be accomplished by changes in price of the cost factors, so that an exact forecast of the resulting effect on income is not possible.

Illustration No. 2. Resources and Present Organization

The following is the description of the resources and productive organization of a farm as it existed in 1921. Normal crop yields have been substituted for actual, as in the previous illustration. These comparisons are made on the basis of normal practices, normal yields, and normal price relations so far as these can be determined.

TABLE XXVIII

DISTRIBUTION OF ACREAGE AND PRODUCTION OF CROPS (PRESENT ORGANIZATION)

	Acres	Yield per acre	Total production
Corn for grain, bu.	48	40	1920
for silage, bu.	21½	6½	140
Oats, bu.	28	45	1260
Barley, bu.	3	25	75
Oats and barley, bu.	17	45	765
Succotash (wheat and oats), bu.	4½	20	90
Tame hay, tons	10½	1½	16
Wild hay, tons	13½	1¼	17
Total crop acres	146		
Pasture (permanent), acres	55		
Farmstead and waste, acres	6		
Total farm area, acres	207		

The buildings on this farm will shelter 25 cows, 20 head of young dairy cattle, 20 brood sows and their pigs, and 200 chickens. The livestock maintained and the production from this stock are shown in Table XXIX.

TABLE XXIX

NUMBER OF HEAD AND PRODUCTION OF PRODUCTIVE LIVESTOCK (PRESENT ORGANIZATION)

Kind of livestock	No. of head	Production
Cows	21	4,200 lbs. butterfat
Bull	1	
Other cattle	16	
Brood sows	12	22,000 lbs. pork
Chickens	200	

A statement of the man labor supply and of the power and equipment utilized under the existing plan of operation are as follows.

TABLE XXX

Labor, Power, and Equipment Supply (Present Organization)

A. Man Labor:
 Two operators (partners) for entire year
 Operator's wife, who assisted with dairy utensils and care of poultry
 Extra help as needed
B. Power:
 Eight horses throughout the year[5]
C. Machinery:
 Fully equipped for all crops grown or suggested

The distribution of the labor actually performed on this farm is shown in Figure 24. The regular supply of labor is computed on the basis of an average or a normal length of working day for the regular workers. The same hours per day are used throughout the year. In actual practice the hours of work per day are increased or decreased according to the press of work. Extra labor hired at irregular intevals is

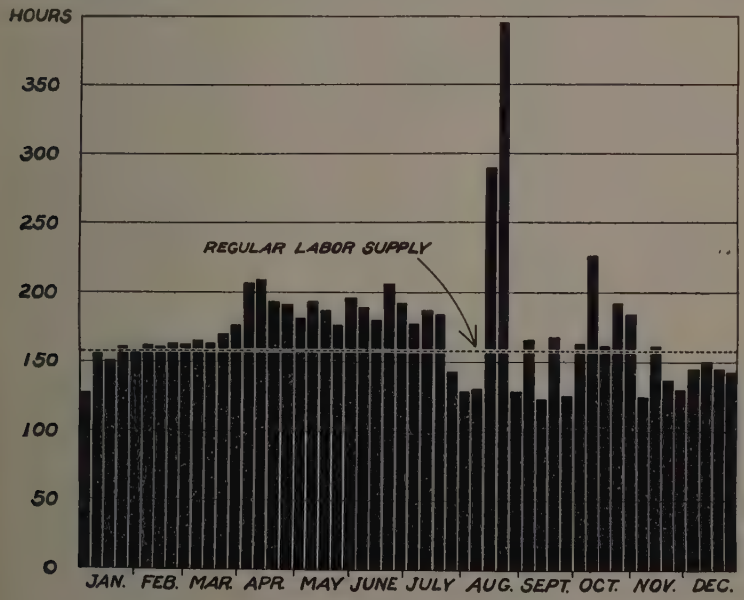


Fig. 24. Distribution of Labor by Weeks and Regular Supply of Labor (Present Organization)

The present labor load is a little too heavy for the regular supply of labor to handle. Even tho working more hours per day during the busy season, the regular labor supply must be supplemented at times by extra hired labor. Exchanging labor with neighbors serves to smooth the labor distribution.

[5] Two colts are kept in addition to the 8 work horses.

not included in the regular labor supply. Through most of the crop season the enterprises of this farm required more labor than that furnished by the regular supply—340 hours of extra labor being hired. The res. was made up by the regular men working more hours per day in rush seasons. Some of the irregularities were smoothed out by exchanging work with neighbors. Most of the exchange work was received during threshing and silo filling the latter part of August. During the slack periods just before and after this peak load period, the regular workers spent considerable time on other farms. As the supply of horse work available exceeded the amount needed at all times except during threshing and silo filling, when it was supplemented by exchange, no distribution of horse work is presented. The following prices are used in the computations of cost and income: corn, 65 cents per bushel; oats, 40 cents per bushel; tame hay, $12 per ton; oilmeal, $50 per ton; butterfat, 50 cents per pound; pork, 8 cents per pound.

Labor rates for the crops affected are shown in Table XXXI. Material expenditures for crops are shown in Table XXXII and the amount of feed and labor used for livestock in Table XXXIII.

TABLE XXXI

HOURS OF LABOR PER ACRE FOR CROP PRODUCTION

	Man	Horse		Man	Horse
Small grain			Alfalfa		
Plowing	2.5	10.0	1st cutting	7.5	10
Seedbed preparation.	1.3	5.2	2d cutting	7.0	9
Seeding	0.8	3.2	3d cutting	5.0	7
Cutting	1.0	4.0	Tame hay, one cutting	7.5	10
Shocking	1.3	..	Wild hay, one cutting	6.5	9
Threshing	3.0	5.0			

TABLE XXXII

MATERIAL EXPENDITURES FOR CROPS

Crop	Seed per acre	Twine per acre	Threshing per bushel
	lbs.	lbs.	cents
Corn for grain	8	..	..
for silage	16	4.5	..
Oats	80	3.5	3.5
Barley	96	2.5	3.5
Oats and barley	80	4.0	3.5
Succotash	92	2.5	4.5
Timothy	4	..	..
Clover	8	..	..
Alfalfa	12	..	..

TABLE XXXIII

AMOUNT OF FEED AND LABOR USED FOR LIVESTOCK PRODUCTION

	Corn	Small grain	Oilmeal	Tame hay	Wild hay	Silage	Skim-milk	Vet serv. and med.	Hours of labor	
									Man	Horse
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.			
Per work horse	1400	1000	..	400	3200			$1.25	85	8.0
Per colt	375	700	..	1200					*	*
Per cow	110	450	68	1300	200	9500		0.65	150	5.0
Per head young cattle	...	300	10	1500	200	4500	2000	0.20	40	1.0
Per 100 lbs. pork	300	50	..				300	0.05	3	0.3
Per 100 chickens	...	3000	..					1.25	130	4.0

* Included with work horses.

All the roughage raised on this farm is fed to livestock, but a considerable amount of corn and oats is sold. The disposition of the crops is indicated in Table XXXIV.

TABLE XXXIV

DISPOSITION OF CROPS PRODUCED (PRESENT ORGANIZATION)

	Total production	Seed	Net production	Amount fed	Amount bought or sold
	lbs.	lbs.	lbs.	lbs.	lbs.
Corn for grain.....	107,520	728	106,792	80,260	26,532 (sold)
for silage	280,000	...	280,000	276,000	
Oats	40,320	2240	38,000	4,672	33,408 (sold)
Barley	3,600	288	3,312	3,312	
Oats and barley....	30,600	1360	29,240	29,240	
Succotash	4,140	414	3,726	3,726	
Tame hay	32,000	...	32,000	58,000	26,000 (bought)
Wild hay	34,000	...	34,000	33,200	

Weaknesses of the Present Organization

As this farm is now organized, the labor demand is too heavy during the crop season to be met by the regular supply of labor. During the year of this study the two operators worked over twelve hours per working day as an average throughout the year and six hours on Sunday. Even then some day help was hired during the crop season. On the other hand, there is hardly enough labor to justify the hiring of another regular man.

The dairy herd is of good dairy breeding, carefully bred and selected for high production. At present they are not fed heavily enough for as high production as their quality and breeding seem to make possible. They are using efficiently the feed they receive, but increased feeding should increase production without a corresponding increase in cost.

Under the present arrangement the fertility of the soil is likely to be depleted. When crops are sold, a great deal more fertility is re-

moved than if the same feed were fed to livestock and only livestock products sold. In reorganizing the farm business some provision should be made to maintain or increase the fertility.

The earning capacity of the farm under the prevailing plan of operation is indicated in Table XXXV.

TABLE XXXV

FINANCIAL RETURNS FROM PRESENT ORGANIZATION

Crop Sales:			
470 bu. corn @ 65c	$ 306		
1040 bu. oats @ 40c	416		
Total crop sales		$ 722	
Livestock Sales:			
4200 lbs. butterfat @ 50c	2100		
4 cows @ $70	280		
2 heifers @ $50	100		
14 veal calves at $9	126		
22,000 lbs. pork @ 8c	1760		
Poultry and eggs	220		
Total livestock sales		4586	
Total crop and livestock sales			$5308
Cash Crop Costs:			
Seed (timothy and clover)	13		
Twine (small grain)	22		
Twine (silage corn)	12		
Threshing	78		
Direct cash crop costs		125	
Cash Livestock Costs:			
Veterinary services and medicine			
Horses (including shoeing)	10		
Cows	14		
Young cattle	4		
Swine	11		
Poultry	3		
Total veterinary services and medicine		42	
Feed and Materials Purchased:			
Tame hay, 13 tons @ $12	156		
Oilmeal, 1700 lbs. @ $2.50	43		
Salt	9		
Grinding feed	35		
Total feed and materials		243	
Direct cash livestock costs		285	
Hired labor		85	
Total cost of extra labor and materials			495
Total returns to organization after deducting extra labor and material costs			$4813

Reorganization Plan—Substituting Equipment for Hand Labor and Increasing the Dairy Herd

A saving of at least 20 man hours per cow could be guaranteed by the installation of a milking machine. This is a conservative estimate in view of the savings actually accomplished on other farms studied where milking machines were installed. It is, therefore, proposed that a machine be obtained to reduce the labor on cows. This substitution of mechanical equipment for hand labor is intended to shorten the length of the working day rather than reduce the amount of hired help.

An increase in the amount fed to the cows should mean a large increase in their production. It is necessary to continue to breed and cull very carefully in order to take full advantage of the heavier feeding. In increasing the feed it is necessary to increase the quality as well as the quantity of the ration. The suggested ration for one cow for a year is as follows:

Corn (as at present), lbs....	110	Alfalfa hay, lbs.	2400
Oats and barley, lbs.....	1700	Silage (as at present), lbs...	9500
Oilmeal, lbs.	125		

The nutritive ratio of the suggested ration is much narrower than of that now fed. Altho the total digestible nutrients have been increased less than 50 per cent, the digestible protein has been more than doubled. The nutritive ration of the suggested ration is 1 : 6.5 as compared with 1 : 10.0 for the present ration. It is estimated that this increase in quantity and quality of the ration will raise the production of butterfat from 200 to 300 pounds per cow annually. This increased dairy production will also furnish additional skimmilk as a protein supplement for hogs.

The cropping system should provide adequately for the maintenance of soil fertility. It is suggested that all crops grown be fed and that the crops be adjusted to provide the maximum quantity of feed of the kinds best suited to the livestock. The corn acreage for both grain and silage is left as at present. Oats, barley, and succotash crops will be dropped and the area of the oats and barley mixture increased to 48 acres. Clover and timothy hay will be dropped and 3 acres of the wild meadow will be plowed up. The rest of the wild meadow is too poorly drained for regular cropping. Hay would be provided by seeding 14 acres of alfalfa in addition to the wild hay. Four acres would also be seeded to alfalfa for hog pasture. The present pasture for cattle would be supplemented by seeding 10 acres of the small grain land to sweet clover each year and using it in the late summer and fall.

TABLE XXXVI

REORGANIZED CROPPING SYSTEM

	Acres	Yield per acre	Total yield	Amount for seed	Amount for feed	Amount sold
Corn for grain, bu.	48	40	1920	13	1907	None
for silage, tons	21.5	6½	140	..	140	None
Oats and barley, bu.	48	45	2160	96	2064	None
Alfalfa, tons*	18	3	42	..	42	None
Wild hay, tons	10.5	1¼	13	..	13	None
Total crop acres	146					
Pasture (permanent), acres	55					
Farmstead and waste, acres	6					
Total farm area, acres	207					

* Only 14 acres cut for hay.

The stock would remain as at present except that the swine enterprise would be expanded to use the grain which is now sold. All stock would be fed as at present except the dairy cows. The hogs would have additional skimmilk and four acres of alfalfa pasture. Sufficient grain would be available for the production of an additional 12,000 pounds of pork. Even with this increase, there would be as much grain per 100 pounds of pork produced as at present and an increase of 70 pounds of skimmilk per 100 pounds.

The distribution of labor under the new plan of operation is indicated in Figure 25. Except during the periods of cutting and putting up alfalfa hay and threshing small grain, there is a slight reduction in the hours per week throughout the year. The increase in labor caused by alfalfa is more than offset by the decrease the rest of the year, the net decrease amounting to 155 hours. The expense for extra hired labor under this plan should be no greater than at present. The present horse labor supply is entirely adequate for the new plan.

This suggested plan of operation provides a net increase of $1280 in the farm income and yet requires no additional buildings and no extra equipment other than the milking machine, for which provision has been made in the statement of expense. The productivity of the soil should be better maintained under this system, as all the crops raised are fed on the farm and more manure is available. The additional sweet clover pasture should provide more adequately for the dairy herd. More skimmilk as well as alfalfa pasture would be available for the hogs.

TABLE XXXVII

FINANCIAL STATEMENT UNDER REORGANIZED PLAN

Crop Sales:			
None			
Livestock Sales:			
Butterfat, 6300 lbs. @ 50c per lb.	$3150		
4 cows @ $70 per head	280		
2 heifers at $50 per head	100		
14 veal calves @ $9 per head	126		
34,000 lbs. pork @ 8c per lb.	2720		
Poultry and eggs	220		
Total sales			$6596
Cash Crop Costs:			
Seed, alfalfa	25		
Seed, sweet clover	12		
Twine, small grain	23		
Twine, silage corn	12		
Threshing	76		
Direct cash crop costs		$148	
Cash Livestock Costs:			
Veterinary services and medicine			
Horses (including shoeing)	10		
Cows	14		
Young cattle	4		
Swine	17		
Poultry	3		
Total veterinary service and medicine		48	
Feed and Materials Purchased:			
Oilmeal, 2800 lbs. @ $2.50	70		
Salt	12		
Grinding feed	70		
Total feed and materials		152	
Direct cash livestock costs		200	
Hired labor (as at present)		85	
Milking machine (25 per cent of first cost)		70	
Total cost of extra labor and materials			503
Total return to organization after deducting extra labor and material costs			$6093
Net increase over present plan of organization			$1280

This system of reorganization allows considerable elasticity, as the swine enterprise can be readily expanded or contracted with an increase or decrease in crop yields. Some elasticity is also possible in the dairy enterprise. As there is a marked tendency for corn and small grain to vary inversely in yields, the balance of these crops tends to stabilize the feed supply. Alfalfa is affected less by drouth than clover and timothy, hence insures a more uniform supply of hay. As one of the principal changes involved in this plan is to utilize more fully the productive capacity of the dairy herd, the advantage over the present plan would hold even with a considerable shift in prices. The other important change is the expansion of the swine enterprise to utilize the concentrates grown on the farm. The skimmilk available for swine feeding gives this farm an advantage in pork production that would still hold in the face of a considerable reduction in pork prices and a marked increase in grain prices.

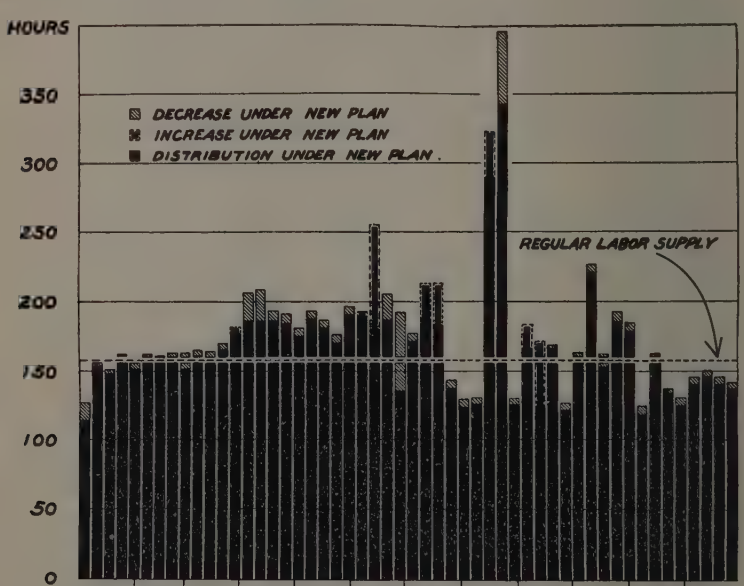


Fig. 25. Distribution of Labor by Weeks Under Proposed Plan, Regular Labor Supply, and Differences Between Present and Proposed Plan

The proposed plan lightens the labor load except during three short periods when work on alfalfa is under way and during threshing. The increases during these periods are more than offset by the labor saving during the rest of the year.

These examples of adjustment in the farm organization are intended only to illustrate a method of using such data as have been presented in forecasting the effect on the farm income of changes in or combinations of enterprises. It is not assumed that all possibilities for improv-

ing the organization were considered. Only specific changes were suggested and the resulting effect on the net income of the farm was determined. This method can, however, be applied quite generally in a study of many possible alternatives.

Altho this method is adapted primarily to the study of a particular farm, it is easily possible by applying it to specific farms representative in type and organization of a considerable group, to draw conclusions of significance for the whole group. The careful and consistent application of this method to the study of the various possible alternatives in the selection, combination, and adjustment of farm enterprises, both by individual farmers and by research and extension workers, should tend to speed up desirable readjustments and stabilize the returns from agricultural production.

SUMMARY

Part I

The study is based on detailed farm records kept on a group of farms in Steele County, Minn., from 1920 to 1924, inclusive.

Steele County is typical of most of the dairy section of southeastern Minnesota in soil, climate, markets, and conditions affecting the dairy industry as well as in agricultural development.

The first settlers came into the county in 1853.

A system of grain farming was first developed, with wheat as the main source of income.

Decreased yields due to continuous cropping with wheat and also to diseases and insect pests led to a shift from grain farming to livestock production.

Since 1880 the amount of livestock has increased steadily from 7 to more than 20 animal units of productive livestock per farm.

During the same period the percentage of the crop acreage in wheat has declined from more than 50 per cent to less than 10 per cent.

In 1924 corn occupied 29 per cent of the crop acreage, hay 28 per cent, oats 23 per cent, and other small grains 16 per cent.

Dairy cattle, swine, and poultry have increased steadily since 1880, but beef cattle and sheep have declined.

For each 100 acres of land there are at present 10.3 milk cows, 44 young dairy cattle, 13.5 swine, 78.9 chickens, and 0.6 sheep.

The principal sale products of these farms are hogs, and cream for manufacture into butter.

The farms studied received 52 per cent of their income from the sale of dairy products and cattle, 29 per cent from swine, 6 per cent from other livestock, 11 per cent from crops, and 2 per cent from miscellaneous sources.

Part II

The amounts of feed and of labor and materials used for livestock and crop production are presented in Part II. The actual expenditures of each farm for one year, the average for each of the five years, and suggested standards are presented. Causes for variations are explained and discussed. The following is a summary of the livestock expenditures.

	5-yr. average	Range	Standard
Per dairy cow (per year):			
Concentrates, lbs	1691	81-2799	1900
Dry roughage, lbs.	2472	1141-4147	2500
Succulent roughage, lbs.	8273	5509-18,284	9000
Pasture, days	182	151-221	160
Man labor, hrs.	166	85-258	150
Horse work, hrs.	9	3-32	10
Butterfat production, lbs.	193	147-285	250
Per head young dairy stock (per year):			
Concentrates, lbs.	373	54-1104	500
Dry roughage, lbs.	1660	707-2185	2000
Succulent roughage, lbs.	3575	1445-7317	4000
Milk, lbs.	1895	806-4839	2025
Pasture, days	65	8-77	60
Man labor, hrs	38	9-83	40
Horse work, hrs.	2	1-13	5
Per 100 lbs. of pork produced:			
Grain, lbs.	428	296-634	375
Tankage, lbs.	3	0-17	
Skimmilk, lbs.	364	22-1154	350
Pasture, days	30	0-70	30
Man labor, hrs.	5.5	2.9-10.7	4
Horse work, hrs.	0.6	0-5.2	0.5
Per 100 chickens (per year):			
Grain, lbs.	2910	1565-8393	3500
Meat scraps, lbs.	9	0-100	
Skimmilk, lbs.	702	0-2367	2000
Man labor, hrs.	201	54-300	175
Horse work, hrs.	4	0-37	4
Eggs laid, number	5093	2519-10,120	6500
Poultry produced, lbs.	318	0-1081	300
Per work horse (per year):			
Grain, lbs.	3020	748-4229	3000
Hay, lbs.	4830	3152-8740	5000
Pasture, days	56	0-160	60
Man labor, hrs.	89	33-114	80
Work performed, hrs.	835	516-1170	1000
Per colt (per year):			
Grain, lbs.	707	140-2323	1000
Hay, lbs.	1709	694-4503	2000
Pasture, days	178	0-278	*
Man labor, hrs.	24	8-85	25

* All season.

A summary of the labor used per acre for crop production is presented below. The labor rates by operations are presented in Part II, together with a statement of seed, twine, and other materials used.

	5-yr. average	Range	Standard
Corn, all work up to harvest time:			
Man hrs.	12.5	10.3-21.1	11
Horse hrs.	31.0	17.7-57.7	33
Tractor hrs.	1.2	0- 3.4	..
Cutting:			
Man hrs.	1.7	1.0- 2.4	1.6
Horse hrs.	5.1	3.1- 7.1	4.8
Shocking:			
Man hrs.	3.7	2.2- 6.6	3.0
Filling silo:			
Man hrs.	11.4	7.2-21.6	11.0
Horse hrs.	14.7	10.2-27.0	13.5
Husking (standing corn):			
Man hrs.	8.8	4.1-11.7	7.5
Horse hrs.	14.6	7.0-26.5	15.0
Husking and shredding:			
Man hrs.	10.5	6-15.7	9.5
Horse hrs.	14.1	9.1-20.5	12.0
Small grain (shock threshed):			
Man hrs.	10.1	7.5-15.0	9.0
Horse hrs.	19.6	9.8-30.9	22.0
Tractor hrs.	1.0	0- 1.5	
Tame hay (1 cutting):			
Man hrs.	6.0	3.8- 9.0	6.0
Horse hrs.	9.5	7.1-15.9	9.0
Alfalfa (3 cuttings):			
Man hrs.	20.3	11.8-29.0	15.0
Horse hrs.	28.4	14.6-34.6	22.0

The range in physical expenditures indicates the wide range in degree of efficiency of production between different farms. The standards of production serve as a measure by which the individual producer may check his own efficiency.

In addition to the direct work on livestock, an additional 3.5 per cent of man labor and 56.5 per cent of horse work are performed as indirect work, such as feed hauling, grinding, etc.

Each year 20 per cent of the crop acreage on the farms studied is manured at an average rate of ten loads per acre.

In addition to the field work on crops, an additional 3.5 per cent of man labor and 1 per cent of horse work is spent on such miscellaneous crop work as cleaning and treating seed, marketing, etc.

Eighty-nine per cent of the man labor and 95 per cent of the horse work on these farms is used in caring for the crop and livestock enterprises. The rest consisted of maintenance or miscellaneous work.

A better distribution of labor throughout the year is made possible by a systematic classification of tasks according to time fixity and weather interference, and fitting these tasks into the labor program on this basis.

Peak labor loads can be handled and the hiring of special day labor avoided by exchanging labor with neighbors.

Tractors were used on 56 per cent of the farms studied.

Sixty per cent of the tractors were 3-plow tractors, 30 per cent 2-plow, and 10 per cent 4-plow.

The average amount of work per tractor annually was 182 hours of drawbar work and 78 of belt work on the home farm and 25 hours of custom work on other farms.

Part III

The choice of adjustment of enterprises for a given farm is based on the following considerations:

1. The adaptation of the enterprise to the conditions of the area.
2. The varying demands of the several enterprises on the resources of the farmer.
3. The inter-relations between enterprises.
4. The possibilities for utilizing relatively fixed resources in the farmer's possession.
5. The facility with which enterprises lend themselves to shifts.
6. Changes in prices of products or in prices of cost factors.

The use of such data as are presented in Part II in forecasting the effect on the net returns of a farm of changes in the choice and adjustment of enterprises, is illustrated. In the first example, alfalfa is substituted for timothy and clover hay, rye is dropped, and the acreage released is planted to winter wheat. This reorganization increases the net income of the farm $605. Another plan suggested involves an increase in corn in place of winter wheat, and a sufficient increase in swine to consume the additional corn.

This plan results in a better distribution and utilization of labor and in an increase of $1137 in the net income.

On another farm it was suggested that the dairy herd be fed more nearly to capacity, and that instead of selling grain it be fed to hogs, thus increasing pork production. This reorganization also provides for the substitution of alfalfa hay for timothy and clover and some minor shifts in the cropping system. This plan would result in an increase of $1280 in the net income. It involves changes in the selection and adjustment of enterprises and in efficiency within the enterprise.

APPENDIX

TABLE XXXVIII

MAN LABOR USED PER ACRE, BY OPERATIONS, FOR CORN UP TO HARVEST TIME, 1922

Farm No.	Acres per farm	Plowing		Disking		Spring-tooth harrowing		Harrowing		Planting	Cultivating		Total hours
		Hours	Times over	Hours	Times over	Hours	Times over	Hours	Times over	Hours	Hours	Times over	
21	90	1.7	1.2	0.1	0.3	1.0	2.3	0.6	1.3	1.1	5.8	5.0	10.3
18	66	4.2	1.7	0.2	0.4	0.1	0.2	0.8	2.7	0.8	4.2	4.3	10.3
5	50	2.8	2.0	0.5	2.0	0.3	0.5	1.3	3.8	1.0	4.6	4.2	10.5
27	30	4.1	1.2	0.6	1.1	..	..	0.8	2.4	0.9	4.4	2.5	10.8
29	30	2.3	1.6	..	..	0.4	0.5	1.3	3.2	1.0	6.3	5.0	11.3
36	50	2.9	1.0	0.3	0.4	0.2	0.3	1.0	2.9	1.0	6.6	4.9	12.0
20	70	1.8	1.3	1.6	2.0	..	..	1.0	4.0	0.8	7.2	5.0	12.4
31	50	4.1	1.3	..	..	0.7	1.6	0.4	1.0	0.9	6.6	4.5	12.7
14	38	2.8	1.0	0.1	0.1	1.0	1.0	0.7	2.0	1.1	7.3	4.8	13.0
24	37	1.7	1.0	..	..	1.4	2.7	0.7	2.0	1.0	8.3	5.9	13.1
25	54	2.6	1.0	1.0	2.0	1.0	0.9	1.0	2.0	1.0	6.8	3.7	13.4
15	54	4.5	2.0	..	..	1.4	1.9	1.5	4.2	0.9	5.1	4.4	13.4
23	42	2.8	1.5	..	..	1.5	1.9	1.2	4.6	0.7	7.3	5.0	13.5
16	37	4.3	1.6	..	..	0.9	0.9	1.2	3.0	0.8	6.6	4.8	13.8
12	38	3.6	2.0	0.4	0.6	1.0	1.0	1.2	2.0	0.8	6.8	4.4	13.8
1	33	3.9	1.3	0.6	1.0	0.5	0.6	1.0	2.0	0.8	7.3	5.4	14.1
26	59	2.9	1.7	0.4	0.6	1.7	1.4	1.5	3.1	0.7	7.6	4.4	14.8
35	30	4.0	1.7	..	..	1.4	1.9	2.4	6.0	0.8	6.5	4.9	15.1
10	40	6.1	1.5	..	..	2.0	3.1	0.9	2.2	0.8	6.6	4.7	16.4
28	33	3.4	1.8	..	..	2.5	3.3	1.4	3.5	0.7	11.1	5.0	19.1
9	47	8.2	2.0	..	..	0.9	1.4	1.2	3.6	1.1	9.7	5.7	21.1
Averages													
21 farms 1922	47	3.4	1.5	0.3	0.5	0.9	1.2	1.1	2.9	0.9	6.7	4.7	13.3
23 " 1920	39	2.4	1.1	0.2	0.4	*	*	1.4	3.4	0.7	7.1	5.4	11.8
21 " 1921	42	2.4	1.1	0.8	1.7	1.1	1.5	1.0	2.3	0.9	6.2	4.4	12.4
22 " 1923	43	2.9	1.2	1.0	1.8	0.7	1.3	0.9	2.6	0.8	5.7	4.1	12.0
23 " 1924	42	3.0	1.3	0.6	1.2	0.8	1.3	1.1	3.5	0.9	6.5	4.7	12.9

* Included with disking.

TABLE XXXIX

HORSE AND TRACTOR WORK USED PER ACRE, BY OPERATIONS, FOR CORN UP TO HARVEST TIME, 1922

Farm No.	Acres per farm	Plowing			Disking			Spring-tooth harrowing			Harrowing			Planting	Cultivating		Total	
		Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Horse hrs.	Times over	Horse hrs.	Tractor hrs.
21	90	0.5	1.5	1.2	..	0.1	0.3	..	1.0	2.3	1.9	0.1	1.3	2.1	13.2	5.0	17.7	2.7
18	66	14.9	..	1.7	0.9	..	0.4	0.4	..	0.2	3.4	..	2.7	1.5	11.2	4.3	32.3	..
5	50	2.3	2.2	2.0	..	0.5	2.0	0.8	0.1	0.5	4.7	..	3.8	2.0	11.3	4.2	21.1	2.8
27	30	12.5	..	1.2	2.5	..	1.1	..	..	..	3.0	..	2.4	1.8	8.8	2.5	28.6	..
29	30	...	2.3	1.6	..	..	..	0.1	0.4	0.5	4.4	0.2	3.2	2.0	12.5	5.0	19.0	2.9
36	50	14.6	..	1.0	0.9	..	0.4	0.6	..	0.3	2.9	..	2.9	2.0	13.5	4.9	34.5	..
20	70	11.7	..	1.3	6.6	..	2.0	..	..	..	4.0	..	4.0	1.6	17.7	5.0	41.6	..
31	50	8.8	1.6	1.3	..	..	..	..	0.7	1.6	1.7	..	1.0	1.7	13.2	4.5	25.4	2.3
14	38	11.1	..	1.0	0.3	..	0.1	4.0	..	1.0	3.0	..	2.0	2.1	14.7	4.8	35.2	..
24	37	1.4	1.3	1.0	..	..	..	1.0	1.2	2.7	2.3	0.2	2.0	2.0	16.6	5.9	23.3	2.7
25	54	10.6	..	1.0	4.2	..	2.0	4.0	..	0.9	2.8	..	2.0	2.0	13.5	3.7	37.1	..
15	54	6.4	2.2	2.0	..	..	..	0.8	1.2	1.9	6.0	..	4.2	1.8	11.8	4.4	26.8	3.4
23	42	7.2	0.9	1.5	..	..	..	..	1.5	1.9	4.5	..	4.6	1.3	14.1	5.0	27.1	2.4
16	37	15.1	..	1.6	..	..	..	3.6	..	0.9	4.8	..	3.0	1.5	13.2	4.8	38.2	..
12	38	5.2	2.0	2.0	0.9	0.1	0.6	4.9	..	1.0	3.8	..	2.0	1.6	15.2	4.4	31.6	2.1
1	33	14.7	..	1.3	2.4	..	1.0	1.6	..	0.6	2.0	..	2.0	1.6	15.5	5.4	37.8	..
26	59	15.9	..	1.7	1.3	..	0.6	7.5	..	1.4	5.3	..	3.1	1.4	15.2	4.4	46.6	..
35	30	13.8	0.5	1.7	..	..	..	4.6	0.2	1.9	8.5	..	6.0	1.6	13.5	4.9	42.0	0.7
10	40	18.5	..	1.5	..	..	..	8.5	..	3.1	3.2	..	2.2	1.5	13.2	4.7	44.9	..
28	33	3.0	2.5	1.8	..	..	..	8.6	0.3	3.3	4.8	0.2	3.5	1.2	20.4	5.0	38.0	3.0
9	47	27.8	..	2.0	..	..	..	3.6	..	1.4	4.7	..	3.6	2.1	19.5	5.7	57.7	..
Averages																		
21 farms, 1922	47	10.2	0.8	1.5	1.1	0.1	0.5	2.4	0.3	1.2	3.8	..	2.9	1.8	14.2	4.7	33.5	1.2
23 " 1920	39	4.5	1.0	1.1	0.2	0.1	0.4	..	..	..	3.5	0.4	3.4	1.4	15.2	5.4	24.8	1.5
21 " 1921	42	4.6	1.1	1.1	1.8	0.4	1.7	3.2	0.4	1.5	3.6	0.1	2.3	1.8	13.3	4.4	28.3	2.0
22 " 1923	43	10.4	0.2	1.2	3.6	0.1	1.8	2.8	0.1	1.3	3.4	..	2.6	1.6	12.0	4.1	33.8	0.4
23 " 1924	42	10.2	0.5	1.3	2.1	0.1	1.2	2.9	0.1	1.3	4.1	..	3.5	1.6	13.7	4.7	34.6	0.7

TABLE XL

MAN LABOR AND HORSE AND TRACTOR WORK USED PER ACRE FOR CORN HUSKED FROM STANDING STALKS, 1922

Farm No.	Acres per farm	Yield bu.	Before harvest			Husking			Total		
			Man hrs.	Horse hrs.	Tractor hrs.	Man hrs.	Horse hrs.	Tractor hrs.	Man hrs.	Horse hrs.	Tractor hrs.
5	25	40	10.5	21.1	2.8	4.6	8.9	..	15.1	30.0	2.8
20	48	31	12.4	41.6	..	4.1	7.0	..	16.5	48.6	..
21*	44	60	10.3	17.7	2.7	7.5	9.5	1.8	17.8	27.2	4.5
27	12	35	10.8	28.6	..	9.1	9.6	..	19.9	38.2	..
18	24	39	10.3	32.3	..	9.6	16.5	..	19.9	48.8	..
36	11	46	12.0	34.5	..	8.3	16.6	..	20.3	51.1	..
31	22	53	12.7	25.4	2.3	8.9	15.4	..	21.6	40.8	2.3
29	10	50	11.3	19.0	2.9	10.5	26.5	..	21.8	45.5	2.9
15	27	58	13.4	26.8	3.4	8.7	17.4	..	22.1	44.2	3.4
24	14	55	13.1	23.3	2.7	9.8	16.0	..	22.9	29.1	2.7
10*	29	38	16.4	44.9	..	6.5	14.4	..	22.9	59.3	..
26	25	59	14.8	46.6	..	8.4	16.8	..	23.2	63.4	..
16	23	52	13.8	38.2	..	10.0	17.7	..	23.8	55.9	..
12	22	36	13.8	31.6	2.1	10.1	15.9	..	23.9	47.5	2.1
23*	23	59	13.5	27.1	2.4	11.7	22.5	2.9	25.2	49.6	5.3
35	10	49	15.1	42.0	0.7	11.7	23.3	..	26.8	65.3	0.9
9*	25	40	21.1	57.7	..	9.4	20.1	..	30.5	77.8	..
Averages											
17 farms, 1922	23	48	13.3	33.5	1.2	8.0	14.5		21.3	48.0	1.2
12 " 1920	19	43	11.8	24.8	1.5	9.9	16.9	..	21.7	41.7	1.5
19 " 1921	20	49	12.4	28.3	2.0	9.5	13.9	..	21.9	42.2	2.0
14 " 1923	16	28	12.0	33.8	0.4	7.7	14.9	..	19.7	48.7	0.4
18 " 1924	20	32	12.9	34.6	0.7	8.8	12.7	..	21.7	47.3	0.7

* Mechanical picker used on these farms; data not included in computing the averages.

TABLE XLI

MAN LABOR USED PER ACRE, BY OPERATIONS, FOR SILAGE CORN, 1922

Farm No.	Acres per farm	Yield tons	Before cutting hrs.	Cutting hrs.	Filling silo hrs.	Total hrs.
20	13	6.9	12.4	1.5	7.2	21.1
18	22	7.6	10.3	1.3	11.2	22.8
21	29	7.0	10.3	2.3	10.6	23.2
14	17	5.4	13.0	1.1	9.7	23.8
27	13	6.1	10.8	1.3	12.1	24.2
29	10	8.1	11.3	1.5	11.6	24.4
24	16	6.9	13.1	2.0	9.9	25.0
5	17	6.5	10.5	1.9	13.8	26.2
31	15	7.6	12.7	1.6	12.1	26.4
25	15	6.7	13.4	2.1	11.3	26.8
26	26	5.8	14.8	1.7	10.3	26.8
12	15	7.7	13.8	1.6	12.1	27.5
35	18	6.6	15.1	1.0	11.5	27.6
1	22	5.6	14.1	2.0	12.1	28.2
36	6	5.4	12.0	2.4	16.5	30.9
23	12	7.5	13.5	1.6	15.8	30.9
15	18	7.9	13.4	1.7	16.3	31.4
10	11	6.4	16.4	1.4	13.7	31.5
16	9	9.0	13.8	1.7	21.6	37.1
28	12	7.1	19.1	1.9	15.2	36.2
9	12	6.7	21.1	1.9	21.2	44.2
Averages						
21 farms, 1922	16	6.8	13.3	1.7	12.5	27.5
23 " 1920	14	6.8	11.8	1.6	11.7	25.1
20 " 1921	14	6.8	12.4	1.9	12.1	26.4
22 " 1923	20	5.3	12.0	1.5	9.4	22.9
22 " 1924	16	6.4	12.9	1.7	11.1	25.7

TABLE XLII

HORSE AND TRACTOR WORK USED PER ACRE, BY OPERATIONS, FOR SILAGE CORN, 1922

Farm No.	Acres per farm	Yield tons	Before cutting		Cutting	Filling silo	Total	
			Horse hrs.	Tractor hrs.	Horse hrs.	Horse hrs.	Horse hrs.	Tractor hrs.
20	13	6.9	41.6	..	4.6	10.5	56.7	..
18	22	7.6	32.3	..	3.9	11.6	47.8	..
21	29	7.0	17.7	2.7	6.9	14.5	39.1	2.7
14	17	5.4	35.2	..	3.3	10.3	48.8	..
27	13	6.1	28.6	..	3.9	13.0	45.5	..
29	10	8.1	19.0	2.9	4.4	16.7	40.1	2.9
24	16	6.9	23.3	2.7	6.0	13.7	43.0	2.7
5	17	6.5	21.1	2.8	4.7	15.9	41.7	2.8
31	15	7.6	25.4	2.3	5.0	15.3	45.7	2.3
25	15	6.7	37.1	..	6.3	14.3	57.7	..
26	26	5.8	46.6	..	5.0	14.0	65.6	..
12	15	7.7	31.6	2.1	4.8	16.9	53.3	2.1
35	18	6.6	42.6	0.7	3.1	14.3	59.4	0.7
1	22	5.6	37.8	..	6.0	13.4	57.2	..
36	6	5.4	34.5	..	7.1	10.2	51.8	..
23	12	7.5	27.1	2.4	4.9	22.2	54.2	2.4
15	18	7.9	26.8	3.4	6.0	19.5	52.3	3.4
10	11	6.4	44.9	..	4.3	16.4	65.6	..
16	9	9.0	38.2	..	5.0	27.0	70.2	..
28	12	7.1	38.0	3.0	5.5	20.5	64.0	3.0
9	12	6.7	57.7	..	6.0	13.4	57.2	..
Averages								
21 farms, 1922	16	6.8	33.5	1.2	5.2	15.7	54.4	1.2
23 " 1920	14	6.8	24.8	1.5	4.8	14.1	43.7	1.5
20 " 1921	14	6.8	28.3	2.0	5.8	16.9	51.0	2.0
22 " 1923	20	5.3	33.8	0.4	4.6	12.4	50.8	0.4
22 " 1924	16	6.4	34.6	0.7	5.2	14.4	54.4	0.7

TABLE XLIII

MAN LABOR AND HORSE AND TRACTOR WORK USED PER ACRE FOR CORN HUSKED AND SHREDDED, 1922

Farm No.	Acres per farm	Yield bu.	Before harvest			Cutting		Shocking	Husking and shredding		Total		
			Man hrs.	Horse hrs.	Tractor hrs.	Man hrs.	Horse hrs.	Man hrs.	Man hrs.	Horse hrs.	Man hrs.	Horse hrs.	Tractor hrs.
29	9	50	11.3	19.0	2.9	1.5	4.4	5.0	6.0	10.0	23.8	33.4	2.9
31	9	40	12.7	25.4	2.3	1.6	5.0	4.2	6.7	10.7	25.3	41.1	2.3
18	10	40	10.3	32.3	..	1.3	3.9	5.2	11.4	14.6	28.2	50.8	..
14	13	55	13.0	35.2	..	1.1	3.3	3.0	11.4	15.5	28.5	54.0	..
1	12	60	14.1	37.8	..	2.0	6.0	3.1	9.5	19.0	28.7	62.8	..
26	6	59	14.8	46.6	..	1.7	5.0	5.0	11.3	10.3	32.8	61.9	..
28	14	45	19.1	38.0	3.0	1.9	5.5	4.0	7.8	9.1	32.8	52.6	3.0
21	8	60	10.3	17.7	2.7	2.3	6.9	4.9	15.7	20.5	33.2	45.1	2.7
24	5	50	13.1	23.3	2.7	2.0	6.0	6.7	13.3	17.8	35.1	47.1	2.7
Averages													
9 farms, 1922	9	51	13.3	33.5	1.2	1.7	5.2	4.7	10.0	14.0	29.7	52.7	1.2
7 " 1920	11	49	11.8	24.8	1.5	1.6	4.8	3.4	11.3	14.8	28.1	44.4	1.5
12 " 1921	9	45	12.4	28.3	2.0	1.9	5.8	4.7	13.6	18.8	32.6	52.9	2.0
11 " 1923	14	23	12.0	33.8	0.4	1.5	4.6	2.8	7.5	10.1	23.8	48.5	0.4
7 " 1924	8	30	12.9	34.6	0.7	1.7	5.2	2.7	10.0	12.7	27.3	52.5	0.7

TABLE XLIV

MAN LABOR AND HORSE AND TRACTOR WORK USED PER ACRE FOR CORN CUT AND SHOCKED, 1922

Farm No.	Acres per farm	Yield tons	Before harvest			Cutting		Shocking	Total		
			Man hrs.	Horse hrs.	Tractor hrs.	Man hrs.	Horse hrs.	Man hrs.	Man hrs.	Horse hrs.	Tractor hrs.
5	8	1.5	10.5	21.1	2.8	1.9	4.7	2.2	14.6	25.8	2.8
18	6	2.5	10.3	32.3	..	1.3	3.9	5.2	16.8	36.2	..
14	4	3.4	13.0	35.2	..	1.1	3.3	3.0	17.1	38.5	..
29	1	1.1	11.3	19.0	2.9	1.5	4.4	5.0	17.8	23.4	2.9
25	39	1.5	13.4	37.1	..	2.1	6.3	2.4	17.9	43.4	..
15	4	2.5	13.4	26.8	3.4	1.7	6.0	4.7	19.8	32.8	3.4
20	2	2.8	12.4	41.6	..	1.5	4.6	6.6	20.5	46.2	..
35	2	1.8	15.1	42.0	0.7	1.0	3.1	4.7	20.8	45.1	0.7
26	4	2.5	14.8	46.6	..	1.7	5.0	5.0	21.5	51.6	..
23	3	3.7	13.5	27.1	2.4	1.6	4.9	6.5	21.6	32.0	2.4
24	3	1.8	13.1	23.3	2.7	2.0	6.0	6.7	21.8	29.3	2.7
28	6	2.5	19.1	38.0	3.0	1.9	5.5	4.0	25.0	43.5	3.0
9	4	3.5	21.1	57.7	..	1.9	6.4	4.5	27.5	64.1	..
Averages											
13 farms, 1922	7	2.1	13.3	33.5	1.2	1.7	5.2	4.7	19.7	38.7	1.2
6 " 1921	5	1.7	12.4	28.3	2.0	1.9	5.8	4.7	19.0	34.1	2.0
14 " 1923	7	1.8	12.0	33.8	0.4	1.5	4.6	2.8	16.3	38.4	0.4
16 " 1924	8	2.0	12.9	34.6	0.7	1.7	5.2	2.7	17.3	39.8	0.7

TABLE XLV

Man Labor Used per Acre, by Operations, for Small Grains, 1922

Farm No.	Acres per farm	Yield lbs.	Plowing		Disking		Spring-tooth harrowing		Harrowing		Seeding	Cutting	Shocking	Stacking	Stack threshing	Shock threshing	Total
			Hrs.	Times over	Hrs.	Times over	Hrs.	Times over	Hrs.	Times over	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.	hrs.
36	26	1731	..	..	1.4	2.0	..	..	0.7	1.0	0.3	0.7	1.1	..	..	3.3	7.5
1	28	1219	2.4	1.0	0.5	1.0	0.4	0.5	0.5	2.0	0.5	1.0	1.5	..	..	2.1	8.9
20	30	1379	1.9	1.4	0.3	0.4	..	..	0.8	4.0	0.5	0.7	1.8	..	..	3.0	9.0
21	116	1321	0.6	0.5	0.4	0.7	0.1	0.3	0.6	1.2	0.5	0.8	1.4	..	..	4.9	9.3
29	44	1675	1.4	1.0	..	..	0.3	0.4	1.1	2.0	0.7	0.7	1.2	..	..	3.9	9.3
28	57	1369	1.6	0.8	..	..	0.9	1.5	0.7	2.0	0.7	0.7	2.0	..	..	2.7	9.3
24	48	1938	2.0	1.0	..	..	0.1	0.3	1.4	4.6	0.7	1.0	1.2	..	..	3.6	10.0
12	32	1784	1.2	1.0	..	..	0.3	0.7	0.8	2.0	1.1	0.9	1.5	..	..	4.4	10.2
27	33	1788	2.8	0.8	0.3	0.5	0.4	0.7	0.4	1.3	0.7	1.0	1.7	..	..	3.5	10.8
6	62	2541	2.7	0.7	0.5	0.7	1.2	1.9	0.7	2.4	0.6	1.0	1.4	..	..	2.9	11.0
18	59	1346	2.4	1.0	0.5	1.0	..	..	0.6	1.9	0.8	0.9	0.9	2.9	2.1	..	11.1
16	44	2126	2.7	1.0	..	..	0.2	0.6	0.8	2.0	0.7	0.7	2.4	..	..	3.9	11.4
14	36	1721	2.8	1.0	0.8	0.1	0.1	0.3	0.8	2.0	0.5	0.9	1.7	..	..	3.9	11.5
23	68	1159	1.7	1.0	..	..	..	..	0.7	2.8	0.9	0.7	1.2	4.7	1.7	..	11.6
31	39	1550	2.7	1.0	..	..	0.9	1.8	0.6	2.0	0.6	0.8	1.3	..	..	4.7	11.6
5	65	959	1.1	0.7	0.4	1.7	0.1	0.2	0.6	2.0	0.7	0.9	1.8	4.5	2.0	..	12.1
26	60	1769	2.0	1.0	0.3	0.6	0.2	0.3	1.2	5.3	0.7	0.8	2.0	3.3	1.9	..	12.4
10	49	1772	4.1	1.0	..	..	0.6	0.6	0.8	2.0	0.8	1.2	2.2	..	..	3.2	12.9
15	52	1898	1.9	0.8	..	..	3.7	5.6	0.6	1.9	0.6	0.8	2.2	..	..	3.7	13.5
9	71	1644	3.9	0.9	0.2	0.3	0.6	1.0	0.4	1.0	0.8	1.1	2.9	..	..	4.4	14.3
25	13	2892	2.9	1.0	0.5	1.0	..	..	0.8	2.2	1.0	0.9	3.5	..	..	5.3	14.9
35	34	1308	2.9	1.1	0.5	1.0	0.4	0.7	1.2	2.2	1.0	0.9	1.8	..	..	6.3	15.0
Averages																	
22 farms, 1922	48	1578	2.2	0.9	0.2	0.5	0.5	0.8	0.7	2.2	0.7	0.9	1.7	(3.8)	(1.9)	3.9	10.8†
23 " 1920	51	1133	2.2	1.0	0.1	0.2	*	*	0.9	3.8	0.7	0.9	1.4	(5.1)	(1.6)	3.4	9.6
21 " 1921	53	1197	2.0	1.0	0.6	1.0	0.5	1.0	0.4	1.4	0.7	1.0	1.6	..	..	3.3	10.1
22 " 1923	48	1662	1.8	0.7	0.2	0.4	0.2	0.5	0.5	1.8	0.7	0.9	1.4	(3.2)	(2.1)	3.5	9.2
23 " 1924	46	1984	1.9	0.8	0.2	0.7	0.3	0.5	0.6	1.9	0.7	0.9	2.2	(7.0)	(2.7)	3.9	10.7

* Included with disking.

† Totals are for shock-threshed grain.

TABLE XLVI

HORSE AND TRACTOR WORK USED PER ACRE, BY OPERATIONS, FOR SMALL GRAIN, 1922

Farm No.	Acres per farm	Yield lbs.	Plowing			Disking			Spring-tooth harrowing		
			Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Tractor hrs.	Times over	Horse hrs.	Tractor hrs.	Times over
36	26	1731	..	..	..	5.1	..	2.0	..	..	.
1	28	1219	9.2	..	1.0	1.9	..	1.0	1.5	..	0.5
20	30	1379	12.4	..	1.4	1.1	..	0.4	..	..	..
21	116	1321	..	0.6	0.5	..	0.4	0.7	..	0.1	0.3
29	44	1675	..	1.4	1.0	..	..	..	0.8	0.1	0.4
28	57	1369	2.7	0.9	0.8	..	..	..	2.2	0.4	1.5
24	48	1938	3.3	1.1	1.0	..	..	..	..	0.1	0.3
12	32	1784	..	1.2	1.0	..	..	..	1.4	..	0.7
27	33	1788	8.3	..	0.8	1.2	..	0.5	1.7	..	0.7
6	62	2541	7.8	..	0.7	1.6	..	0.7	4.5	..	1.9
18	59	1346	8.9	..	1.0	1.9	..	1.0	..	..	..
16	44	2126	9.2	..	1.0	..	..	..	0.6	..	0.6
14	36	1721	11.1	..	1.0	0.3	..	0.1	0.5	..	0.3
23	68	1159	3.1	0.9	1.0	..	..	..	..	..	..
31	39	1550	7.9	0.6	1.0	..	..	..	2.3	0.3	1.8
5	65	959	0.9	0.8	0.7	..	0.4	1.7	0.4	..	0.2
26	60	1769	12.0	..	1.0	1.3	..	0.6	0.9	..	0.3
10	49	1772	12.1	..	1.0	..	..	..	2.1	..	0.6
15	52	1898	3.5	0.7	0.8	..	..	..	1.5	..	5.6
9	71	1644	11.5	..	0.9	1.0	..	0.3	2.4	..	1.0
25	13	2892	11.6	..	1.0	2.1	..	1.0	..	..	..
35	34	1308	8.7	0.7	1.1	1.4	..	1.0	..	0.4	0.7
Averages											
22 farms, 1922.....	48	1578	6.0	0.4	0.9	0.6	0.1	0.5	1.1	0.1	0.8
23 " 1920.....	51	1133	4.2	1.0	1.0	0.2	..	0.2	*	*	*
21 " 1921.....	53	1197	4.2	0.9	1.0	1.2	0.2	1.0	1.6	0.2	1.0
22 " 1923.....	48	1662	6.1	0.2	0.7	0.9	..	0.4	1.0	..	0.5
23 " 1924.....	46	1984	6.5	0.2	0.8	0.5	0.1	0.7	1.1	..	0.5

* Included with disking.

TABLE XLVI.—*Continued*

Farm No.	Acres per farm	Yield lbs.	Harrowing			Seeding hrs.	Cutting		Stacking hrs.	Stack threshing hrs.	Shock threshing hrs.	Total	
			Horse hrs.	Tractor hrs.	Times over		Horse hrs.	Tractor hrs.				Horse hrs.	Tractor hrs.
36	26	1731	1.3	..	1.0	0.5	3.0	..	..	..	3.3	13.2	..
1	28	1219	2.0	..	2.0	2.1	3.9	..	..	..	3.1	23.7	..
20	30	1379	3.1	..	4.0	2.1	2.6	..	..	..	5.2	26.5	..
21	116	1321	1.7	0.04	1.2	2.2	..	0.4	..	..	5.9	9.8	1.5
29	44	1675	4.3	..	2.0	2.8	2.8	..	..	..	5.0	15.7	1.5
28	57	1369	2.9	..	2.0	2.7	2.9	..	..	..	3.8	17.2	1.3
24	48	1938	4.9	..	4.6	2.9	3.9	..	..	..	4.6	19.6	1.2
12	32	1784	3.0	..	2.0	3.6	3.5	..	..	..	6.6	18.1	1.2
27	33	1788	1.5	..	1.3	2.1	3.8	..	..	..	4.7	23.3	..
6	62	2541	1.7	..	2.4	1.7	3.5	..	..	..	5.1	25.9	..
18	59	1346	2.3	..	1.9	3.1	3.4	..	3.9	0.7	..	24.2	..
16	44	2126	3.2	..	2.0	2.0	2.7	..	..	..	5.6	23.3	..
14	36	1721	3.3	..	2.0	2.1	3.5	..	..	..	5.8	26.6	..
23	68	1159	2.9	..	2.8	1.8	2.8	..	6.2	0.5	..	17.3	0.9
31	39	1550	2.2	0.04	2.0	2.4	2.5	..	..	..	5.9	23.2	0.9
5	65	959	2.4	..	2.0	2.9	3.6	..	5.5	0.4	..	16.1	1.2
26	60	1769	4.3	..	5.3	2.6	3.2	..	4.8	1.2	..	30.9	..
10	49	1772	3.2	..	2.0	1.6	3.6	..	..	..	4.5	27.1	..
15	52	1898	2.2	..	1.9	1.8	3.3	..	..	..	4.4	16.7	0.7
9	71	1644	1.5	..	1.0	3.0	4.3	..	..	..	6.7	30.4	..
25	13	2892	2.8	..	2.2	2.4	3.7	..	..	..	7.6	30.2	..
35	34	1308	3.9	0.1	2.2	2.9	3.4	..	..	..	7.0	27.3	1.2
Averages													
22 farms, 1922.....	48	1578	2.7	..	2.2	2.4	3.0	..	(5.1)	(0.7)	5.3	21.1†	0.6†
23 " 1920	51	1133	2.6	0.1	3.8	2.4	2.7	0.1	(5.5)	(0.4)	4.3	16.4	1.2
21 " 1921.....	53	1197	1.6	..	1.4	2.3	2.5	0.2	..	..	5.0	18.4	1.5
22 " 1923.....	48	1662	1.9	..	1.8	2.3	2.6	0.1	(4.4)	(0.4)	5.3	20.1	0.8
23 " 1924.....	46	1984	2.2	..	1.9	2.4	3.0	0.1	(4.7)	(1.8)	6.3	22.0	1.0

† Totals are for shock-threshed grain.

TABLE XLVII

MAN LABOR USED PER ACRE, BY OPERATIONS, FOR TAME HAY, 1922

Farm No.	Acres per farm	Yield tons	Percentage cut twice	Mowing hrs.	Raking hrs.	Hauling and stacking hrs.	Total hrs.
10	16	1.2	..	1.1	0.4	2.6	4.1
27	12	3.3	..	1.0	0.6	3.1	4.7
24	23	1.4	..	1.2	0.5	3.4	5.1
31	20	1.3	..	0.7	0.6	3.8	5.1
26	45	2.1	*	1.0	0.4	3.7	5.1
21	19	2.2	*	1.0	0.7	3.5	5.2
29	16	1.3	..	1.0	0.7	3.9	5.6
28	23	1.5	26	1.7	0.8	3.8	6.3
6	43	1.3	..	1.1	0.3	5.2	6.6
35	9	1.9	..	1.1	0.4	5.5	7.0
20	22	1.7	*	1.5	0.7	4.9	7.1
14	9	2.6	100	1.9	1.3	4.4	7.6
18	7	2.0	..	1.0	0.8	6.2	8.0
1	14	1.7	100	2.2	1.0	5.4	8.6
25	22	1.9	..	2.0	1.0	6.0	9.0
15	31	1.9	..	1.1	0.4	8.1	9.6
16	31	2.0	60	1.6	0.7	7.6	9.9
12	9	2.4	65	1.7	0.6	7.8	10.1
5	18	1.1	..	1.1	1.0	9.0	11.1
Averages							
19 farms, 1922	21	1.7	14	1.3	0.6	5.2	7.1
22 " 1920	18	1.8	49	1.7	0.8	7.3	9.8
19 " 1921	21	1.4	27	1.5	0.7	6.2	8.4
20 " 1923	20	1.1	11	1.2	0.6	4.1	5.9
19 " 1924	17	1.5	32	1.4	0.7	4.8	6.9

* Second crop cut for seed; labor not included here.

TABLE XLVIII

HORSE WORK USED PER ACRE, BY OPERATIONS, FOR TAME HAY, 1922

Farm No.	Acres per farm	Yield tons	Percentage cut twice	Mowing hrs.	Raking hrs.	Hauling and stacking hrs.	Total hrs.
10	16	1.2	..	2.2	0.8	4.8	7.8
27	12	3.3	..	2.0	1.2	7.4	10.6
24	23	1.4	..	2.4	1.0	5.4	8.8
31	20	1.3	..	1.4	1.2	7.5	10.1
26	45	2.1	*	2.0	0.8	7.4	10.2
21	19	2.2	*	2.0	1.4	3.7	7.1
29	26	1.3	..	2.0	1.4	6.5	9.9
28	23	1.5	26	3.4	1.6	5.4	10.4
6	43	1.3	..	2.2	0.6	7.0	9.8
35	9	1.9	..	2.2	0.8	12.9	15.9
20	22	1.7	*	3.0	1.4	7.3	11.7
14	9	2.6	100	3.8	2.6	7.8	14.2
18	7	2.0	..	2.0	1.6	12.3	15.9
1	14	1.7	100	4.4	2.0	10.5	16.5
25	22	1.9	..	4.0	2.0	5.8	11.8
15	31	1.9	..	2.2	0.8	11.7	14.7
16	31	2.0	60	3.2	1.4	8.2	12.8
12	9	2.4	65	3.4	1.2	11.2	15.8
5	18	1.1	..	2.2	2.0	11.0	15.2
Averages							
19 farms, 1922	21	1.7	14	2.6	1.2	7.7	11.5
22 " 1920	18	1.8	49	3.4	1.6	9.0	14.0
19 " 1921	21	1.4	27	3.0	1.4	8.7	13.1
20 " 1923	20	1.1	11	2.4	1.2	5.8	9.4
19 " 1924	17	1.5	32	2.8	1.4	7.7	11.9

* Second crop cut for seed; labor not included here.

TABLE XLIX

MAN LABOR USED PER ACRE, BY OPERATIONS, FOR ALFALFA, 1922

Farm No.	Acres per farm	Yield tons	Mowing hrs.	Raking hrs.	Tedding, turning, cocking, hrs.	Hauling and stacking hrs.	Total hrs.
First cutting							
16	3	2.1	0.9	0.6	1.2	2.7	5.4
1	5	1.6	1.2	0.4	..	4.2	5.8
31	4	1.6	1.1	0.8	..	4.4	6.3
14	5	1.2	1.4	1.0	..	5.2	7.6
9	11	2.1	1.1	0.6	..	6.6	8.3
12	9	2.5	0.9	0.7	..	6.7	8.3
21	4	1.4	1.1	0.7	0.6	6.1	8.5
15	2	2.6	1.0	0.5	2.6	5.1	9.2
35	7	1.3	1.0	0.7	1.0	6.6	9.3
20	4	2.0	1.0	0.5	..	7.9	9.4
27	4	3.1	1.4	1.4	3.6	5.0	11.4
36	3	2.6	1.8	1.1	8.5	8.1	19.5
12 farms, 1922	5	2.0	1.1	0.7	0.9	6.0	8.7
3 " 1920	2	3.0*	1.5	1.0	3.9	6.2	12.6
6 " 1921	5	1.7	1.3	0.6	0.6	6.6	9.1
16 " 1923	6	1.1	1.1	0.5	0.6	3.8	6.0
20 " 1924	8	1.2	1.2	0.6	0.6	4.8	7.2
Second cutting							
16	3	1.2	0.9	0.5	..	1.2	2.6
35	7	1.0	1.2	0.3	0.3	2.8	4.6
21	4	0.8	1.1	0.8	..	3.3	5.2
1	5	1.1	1.2	0.4	..	3.6	5.2
14	5	0.6	1.0	2.0	..	2.3	5.3
36	3	1.1	1.5	0.4	1.1	2.6	5.6
31	4	1.1	1.1	0.8	..	3.8	5.7
27	4	1.4	1.0	0.5	2.2	2.4	6.1
12	9	1.2	1.0	0.4	..	4.8	6.2
20	4	1.2	1.0	1.0	..	4.7	6.7
9	11	1.6	1.3	0.3	..	5.6	7.2
15	2	1.5	1.3	0.5	4.1	7.7	13.6
Averages							
12 farms. 1922	5	1.2	1.1	0.6	0.4	3.9	6.0
3 " 1920	2	*	1.8	0.7	0.5	4.3	7.3
6 " 1921	5	1.3	1.2	0.6	0.5	5.0	7.3
16 " 1923	6	1.2	1.1	0.5	0.2	3.3	5.1
20 " 1924	7	1.1	1.3	0.6	0.7	3.9	6.5
Third cutting							
31	3	0.5	0.7	0.3	..	2.0	3.0
35	7	0.9	0.9	0.6	..	2.1	3.6
16	3	0.6	0.9	0.5	..	2.4	3.8
36	3	0.4	0.7	0.7	0.7	1.8	3.9
14	3	0.7	1.1	0.1	..	2.8	4.0
20	4	0.7	1.2	0.5	..	2.5	4.2
9	11	1.2	1.4	1.0	..	4.0	6.4
12	9	1.4	1.0	0.3	..	5.9	7.2
1	5	0.7	0.9	0.7	3.4	3.1	8.1
Averages							
9 farms, 1922	5	1.0	1.0	0.7	0.3	3.5	5.5
2 " 1920	3	*	1.9	0.3	0.2	2.0	4.4
5 " 1921	6	0.7	1.2	0.9	0.9	4.6	7.6
9 " 1923	7	0.5	1.3	0.6	0.1	2.3	4.3
16 " 1924	7	0.7	1.2	0.5	0.2	2.1	4.0

* Entire yield reported for first cutting.

TABLE L

HORSE WORK USED PER ACRE, BY OPERATIONS, FOR ALFALFA, 1922

Farm No.	Acres per farm	Yield tons	Mowing hrs.	Raking hrs.	Tedding, turning, cocking, hrs.	Hauling and stacking hrs.	Total hrs.
First cutting							
16	3	2.1	1.8	1.2	1.2	1.8	6.0
1	5	1.6	2.4	0.8	..	8.4	11.6
31	4	1.6	2.2	1.6	..	5.4	9.2
14	5	1.2	2.8	2.0	..	6.2	11.0
9	11	2.1	2.2	1.2	..	8.9	12.3
12	9	2.5	1.8	1.4	..	9.1	12.3
21	4	1.4	2.2	1.4	1.1	5.0	9.7
15	2	2.6	2.0	1.0	..	5.1	8.1
35	7	1.3	2.0	1.4	..	10.1	13.5
20	4	2.0	2.0	1.0	..	5.4	8.4
27	4	3.1	2.8	2.8	..	9.1	14.7
36	3	2.6	3.6	2.2	..	13.2	19.0
Averages							
12 farms, 1922	5	2.0	2.2	1.4	0.1	7.8	11.5
3 " 1920	2	3.0*	3.0	2.0	0.6	7.2	12.8
6 " 1921	5	1.7	2.6	1.2	0.3	7.2	11.3
16 " 1923	6	1.1	2.2	1.0	0.1	5.1	8.4
20 " 1924	8	1.2	2.4	1.2	0.2	7.0	10.8
Second cutting							
16	3	1.2	1.8	1.0	..	1.2	4.0
35	7	1.0	2.4	0.6	..	4.5	7.5
21	4	0.8	2.2	1.6	..	2.8	6.6
1	5	1.1	2.4	0.8	..	6.2	9.4
14	5	0.6	2.0	4.0	..	2.9	8.9
36	3	1.1	3.0	0.8	..	5.1	8.9
31	4	1.1	2.2	1.6	..	7.5	11.3
27	4	1.4	2.0	1.0	..	4.8	7.8
12	9	1.2	2.0	0.8	..	9.1	11.9
20	4	1.2	2.0	2.0	..	7.9	11.9
9	11	1.6	2.6	0.6	..	8.4	11.6
15	2	1.5	2.6	1.0	..	5.1	8.7
Averages							
12 farms, 1922	5	1.2	2.2	1.2	..	6.1	9.5
3 " 1920	2	*	3.6	1.4	0.1	5.8	10.9
6 " 1921	5	1.3	2.4	1.2	..	5.8	9.4
16 " 1923	6	1.2	2.2	1.0	..	4.3	7.5
20 " 1924	7	1.1	2.6	1.2	0.3	5.3	9.4
Third cutting							
31	3	0.5	1.4	0.6	..	2.0	4.0
35	7	0.9	1.8	1.2	..	2.7	5.7
16	3	0.6	1.8	1.0	..	1.8	4.6
36	3	0.4	1.4	1.4	..	3.6	6.4
14	3	0.7	2.2	0.2	..	5.6	8.0
20	4	0.7	2.4	1.0	..	3.4	6.8
9	11	1.2	2.8	2.0	..	5.6	10.4
12	9	1.4	2.0	0.6	..	7.8	10.4
1	5	0.7	1.8	1.4	..	6.2	9.4
Averages							
9 farms, 1922	5	1.0	2.0	1.4	..	4.9	8.3
2 " 1920	3	*	3.8	0.6	..	3.7	8.1
5 " 1921	6	0.7	2.4	1.8	0.3	6.0	10.5
9 " 1923	7	0.5	2.6	1.2	..	3.2	7.0
16 " 1924	7	0.7	2.4	1.0	0.2	3.1	6.7

* Entire yield reported for first cutting.

TABLE LI

MAN LABOR USED PER ACRE, BY OPERATIONS, FOR WILD HAY, 1922

Farm No.	Acres per farm	Yield tons	Mowing hrs.	Raking hrs.	Hauling and stacking hrs.	Total hrs.
14	12	1.6	1.2	0.8	2.8	4.8
20	3	1.1	1.4	0.7	3.2	5.3
18	13	2.0	1.4	0.5	3.8	5.7
35	4	1.1	1.6	0.7	4.1	6.4
23	25	1.8	1.3	0.5	4.6	6.4
27	6	1.4	1.1	0.6	5.5	7.2
36	4	1.0	1.9	0.5	5.6	8.0
5	24	1.1	0.8	0.7	6.6	8.1
21	22	2.6	1.6	0.7	6.2	8.5
9	10	1.2	1.4	0.7	6.5	8.6
15	9	1.8	0.9	0.7	7.1	8.7
12	3	1.1	1.1	0.4	7.6	9.1
Averages						
12 farms, 1922	11	1.5	1.3	0.6	5.3	7.2
14 " 1920	14	1.1	1.3	0.6	4.8	6.7
13 " 1921	13	0.7	1.3	0.5	4.8	6.6
9 " 1923	14	0.6	1.3	0.6	2.4	4.3
8 " 1924	16	0.9	1.2	0.5	2.2	3.9

TABLE LII

HORSE WORK USED PER ACRE, BY OPERATIONS, FOR WILD HAY, 1922

Farm No.	Acres per farm	Yield tons	Mowing hrs.	Raking hrs.	Hauling and stacking hrs.	Total hrs.
14	12	1.6	2.4	1.6	4.0	8.0
20	3	1.1	2.8	1.4	4.6	8.8
18	14	2.0	2.8	1.0	7.6	11.4
35	4	1.1	3.2	1.4	6.4	11.0
23	25	1.8	2.6	1.0	8.8	12.4
27	6	1.4	2.2	1.2	11.0	14.4
36	4	1.0	3.8	1.0	11.1	15.9
5	24	1.1	1.6	1.4	8.1	11.1
21	22	2.6	3.2	1.4	6.9	11.5
9	10	1.2	2.8	1.4	6.6	10.8
15	9	1.8	1.8	1.4	10.3	13.5
12	3	1.1	2.2	0.8	11.4	14.4
Averages						
12 farms, 1922	11	1.5	2.6	1.2	7.6	11.4
14 " 1920	14	1.1	2.6	1.2	5.9	9.7
13 " 1921	13	0.7	2.6	1.0	6.9	10.5
9 " 1923	14	0.6	2.6	1.2	3.4	7.2
8 " 1924	16	0.9	2.4	1.0	3.5	6.9

TECHNICAL BULLETIN 45 DECEMBER, 1926

University of Minnesota
Agricultural Experiment Station
IN CO-OPERATION WITH
UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF FARM POPULATION
AND RURAL LIFE

The Marketing Attitudes of Minnesota Farmers

Carle C. Zimmerman and John D. Black
Division of Agricultural Economics

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	3
Method of conducting the study	4
The sample	5
The communities studied	9
Marketing institutions	16
What farmers believe and know about co-operative marketing and its problems	20
Relation between attitudes and co-operative experience	27
What farmers think and know about marketing agencies	31
Reasons for attitudes toward private marketing agencies	40
What farmers think about farmers' organizations	43
Attitudes toward national economic policy	47
Reasons for attitudes regarding tariffs	48
Summary	48
Significance of co-operative marketing	51
Relation to extension work in marketing	53

ILLUSTRATIONS

	Page
Fig. 1. Percentage of crop area devoted to corn	6
2. Percentage of crop area devoted to wheat	7
3. Percentage of crop area devoted to potatoes in 1923	8
4. Average size of farms	9
5. Average value per acre of land	10
6. Correlation between co-operative experience and attitudes toward co-operation	27

MARKETING ATTITUDES OF MINNESOTA FARMERS[1]

By Carle C. Zimmerman and John D. Black

INTRODUCTION

The purposes of this study were to discover the attitudes of the farmers of Minnesota toward marketing problems, and particularly toward co-operation; to discover the genesis of these attitudes, and to point out their significance in programs of organization and education in the field of marketing. Some of the important relationships between farmers' marketing attitudes and successful marketing, are the following:

1. Efficient marketing is partly a matter of proper attitudes. A simple illustration of this is the attitude of farmers toward quality of products. Too many farmers are indifferent on this subject. They are inclined to feel that it is their business to produce and that of the other fellow to find the consumer. If farmers continue to send their products to market without regard to the size, condition, and quality wanted by consumers, the large spread between producer and consumer prices will continue.

2. Failures in farmers' marketing organizations often arise through social causes which supplement the ordinary economic hazards of a business. Important among these social causes are the attitudes of the members toward marketing and co-operation problems. Membership loyalty, so vital to the success of every co-operative organization, is no doubt a problem of fundamental human traits and behavior.

3. Membership relations between individuals and groups are a most important social phase of every co-operative organization. Shall an organization have locals? When and where shall such locals be established? Who shall be their leaders? What relations shall a member have with his neighbor members and with the organization as a whole? Shall a co-operative be organized from the bottom up or from the top down? What should be the source and the extent of the farmers' information concerning marketing? Shall there be membership drives? Who shall conduct them? The answer to all these questions is closely bound up with farmers' attitudes on many points.

[1] This study was a joint project between the Division of Agricultural Economics, of the Minnesota Agricultural Experiment Station, and the Division of Farm Population and Rural Life of the Bureau of Agricultural Economics of the United States Department of Agriculture. Dr. Zimmerman made the field study. Dr. C. J. Galpin, of the United States Department of Agriculture, assisted in directing the project.

It was originally presented to the Faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

The term "attitude" is one whose definition has recently provoked considerable discussion. As here used, it means simply an opinion or point of view on a subject, expressed or defined in response to a direct question. In most cases, the behavior of the individuals is correlated with their opinions thus expressed. Those who said that they believed in co-operation were, as a rule, members or patrons of such organizations. Altho the correlation between expressed attitude and actual behavior was not perfect, it was high enough for practical purposes.[2]

METHOD OF CONDUCTING THE STUDY

The data were obtained by the survey method. After a careful analysis of the territory, nine communities were chosen for detailed study, and from 30 to 50 farmers were interviewed in each. The farmers solicited were chosen by going north, south, east, and west from town and taking each farmer along the road until a quarter of the number desired had been seen. A total of 345 were interviewed, an average of 38 in a community. This is one out of every 520 farmers in the state, and one out of every 80 in the ten counties in which the communities were located. These data were analyzed (1) to find the attitudes of the farmers regarding the problems under investigation, and (2) to explain the variations between communities and between individuals in order to determine the significant factors influencing marketing behavior.

The data obtained consisted of:

1. Pertinent information relating to the individual farm business, including acreage of crops, number of head of livestock, sale policies, etc.
2. Farming experience and land tenure history of the operator.
3. Education, reading habits, social and political history of the operator.
4. Co-operative experience and organizations in which the farmer had participated.
5. The attitudes of the farmer regarding certain marketing institutions and practices, and a number of other economic and social phenomena with which the farmer had had experience.
6. The farmer's explanation of his own behavior on attitudes.
7. The explanation of the farmer's attitudes by a "community adviser" who had known him personally for some years.[3]

[2] The term "attitude" became popular through the works of the psycho-analysts, especially Freud, Jung, and Adler. It was introduced into "Social Psychology" by W. I. Thomas and Florion Zwaniecki. It has been discussed by Park and Burgess, L. L. Bernard, Floyd Allport, Emory Bogardus, J. M. Williams, R. H. Gault, Ellsworth Faris, C. H. Cooley, James H. Leuba, E. C. Lindeman, and others.

[3] This community adviser was a local man of considerable knowledge and intelligence who was consulted regarding each farmer. He gave considerable data which the farmers would not or could not tell about themselves, such as emotional bias, etc. See E. C. Lindeman, "Social Discovery," pp. 187-200 for a discussion of this method.

8. An analysis of the social problems of marketing for each community by local leaders.

The Sample[4]

The sample was chosen with a view to representing the important systems of farming prevailing in the state and also such social characteristics as nationality and traditional backgrounds. Studies already made have shown that the principal agricultural areas of Minnesota consist of the corn belt in the southwestern section of the state; the small-grain belt in the northwestern area and in the Red River Valley; the potato belt just north of the Twin Cities, extending through the cut-over section into the Red River Valley; and the dairy belt in the southeastern and central sections.[5] Figures 1, 2, and 3 show the locations of several of these areas and of the communities studied. The problem consisted of sampling these areas, and at the same time covering the marketing experience and the social characteristics of the farmers.

The most important social characteristic of Minnesota farmers is their nativity. The foreign-born in the survey were 28 per cent of the total and were of 13 nationalities. Their average residence in the United States was 32 years; and in the community 19 years. The foreign-born in the communities varied from 14 to 80 per cent. Three-fifths of these were Scandinavians, and the rest were mostly Germans and Finlanders. The first generation of native-born were proportionately more of German origin, because the Germans settled in the state earlier than the Scandinavians.

The average age of the operators interviewed was 44.5 years. Only one community differed from the average more than 2 years. The average years in school were 7.7, the average in the communities varying from 6.7 to 9.2 years. A daily paper came into 78 per cent of the homes. The average farmer subscribed to 4.1 other papers. Eighty per cent had telephones, the range being from 58 to 100 per cent in the different communities. Automobiles were owned by 85 per cent of the farmers interviewed, the percentages ranging from 66 to 96 for the separate communities. Only three of the farmers did not read or speak English, and only two others could not write.

A comparison of the sample with the census statistics shows rather close agreement with respect to all important economic and other social characteristics—crops grown, livestock kept, size of farms, tenancy, nativity, nationality origin. Figures 4 and 5 show the relationship of

[4] This sampling was conducted and tested according to the principles given by G. Udny Yule in "An Introduction to the Theory of Statistics," and by F. S. Chapin, in "Field Work in Social Research."

[5] Minn. Tech. Bull. 4 and 26, and Agr. Exp. Sta. Bull. 195; and U. S. Dept. of Agr. Bull. 1295. Technical Bulletin 26 is no longer available for distribution.

the farmers studied to the different sizes of farms and different land values of the state. It is no doubt true, however, that farmers near town were included proportionately more than those living farther away. Furthermore, it is the opinion of the authors that the necessity of securing farmers who could discuss the questions raised gave a sample which is somewhat above the average in intelligence and degree of success in farming. The authors think the sample may be 10 per cent above the average in these respects.

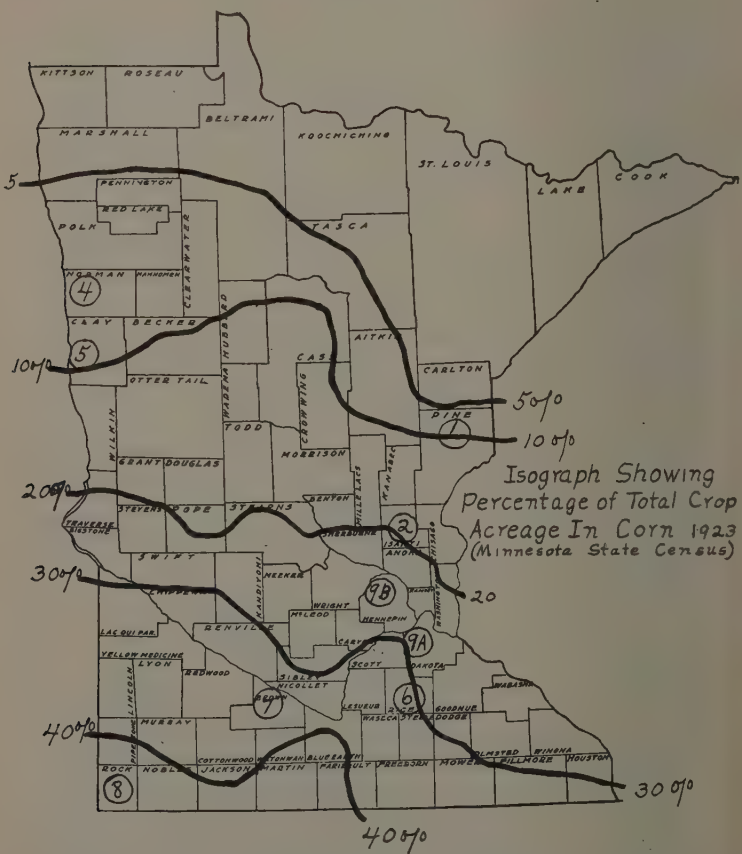


Fig. 1 Percentage of Crop Area Devoted to Corn

In 1923 southern Minnesota had more than 30 per cent and southwestern Minnesota more than 40 per cent, of the crop area devoted to corn. The numbered circles are the communities studied.

Table I summarizes the co-operative experience of the 345 farmers. Only 32 had never been members of co-operative marketing organizations. More than half had a combined membership in all types of co-operative marketing organizations of 10 years or less.

In addition to this representative sample of farmers, interviews were obtained from 100 other persons, as county agricultural agents, co-operative employees, farm leaders, and dealers in farm products.

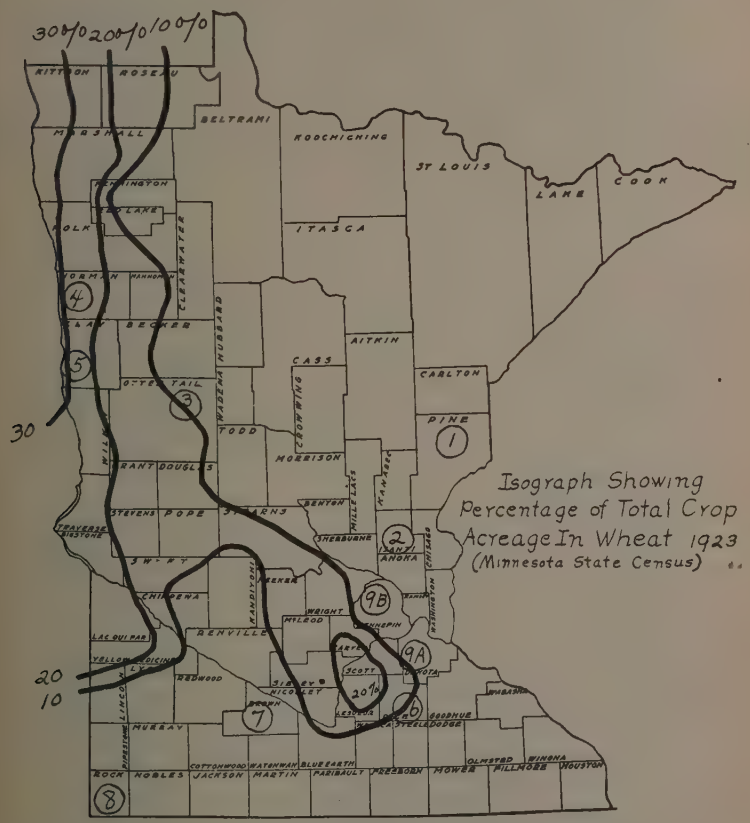


Fig. 2. Percentage of Crop Area Devoted to Wheat

The wheat and small-grain belt is in the west, especially in the Red River Valley. The numbered circles are the communities studied.

TABLE I

YEARS OF CO-OPERATIVE EXPERIENCE OF THE FARMERS STUDIED*

Amount of experience	No. of farmers	Percentage of total studied
Years		
None	32	9.3
1- 5	96	27.8
6-10	67	19.4
11-15	54	15.7
16-20	19	5.5
21-25	19	5.5
26-30	18	5.2
31-35	13	3.8
More than 36	27	7.8
Total	345	100.0

* Experience was taken to mean number of years of membership. A farmer who had belonged to a creamery 4 years and a shipping association 1 year was credited with 5 years experience. Practically the same results would have been obtained in the diversified farming sections had the number of associations of which the farmer was a member been used.

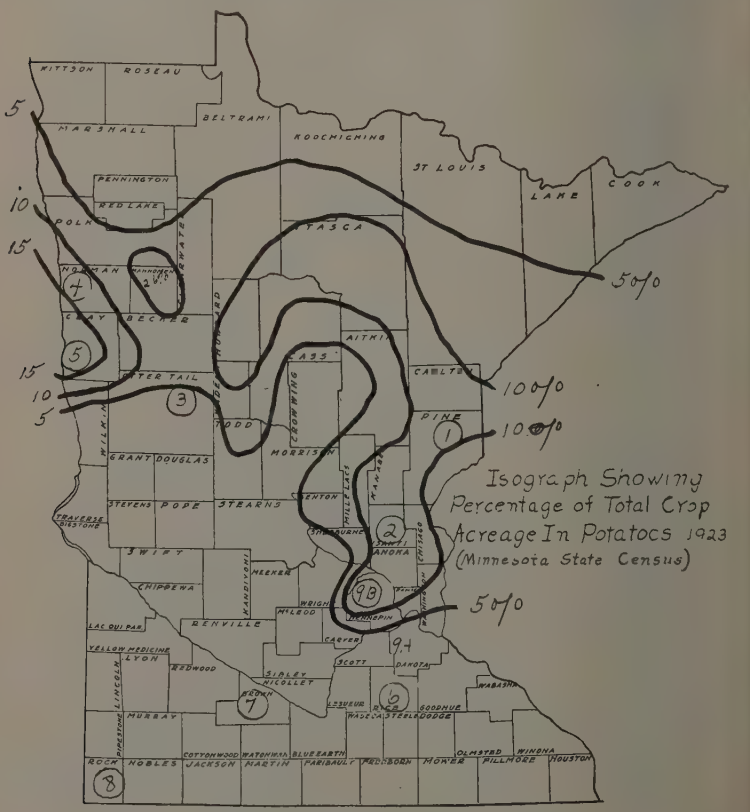


Fig. 3. Percentage of Crop Area Devoted to Potatoes in 1923

The numbered circles are the communities studied. The potato territory may be divided into an eastern and a western belt.

The Communities Studied

Askov, in Pine County, is a Danish colony of 2000 people located in the old potato belt and cut-over territory. The village has a population of 250. The community first sprang up in 1904 as a result of colonization by the Danish Lutheran Church. Sources of income, in order of importance, are butterfat, rutabagas, potatoes, poultry, and livestock. Farms averaged 82 acres in size, and nearly all who farmed were owner-operators. The people not only belonged to the same church and were of the same nationality, but 33 out of the 41 were born in Denmark. Their average residence in the United States was 25 years. One outstanding characteristic of this community was its attempt to reproduce in the United States the Danish system of rural

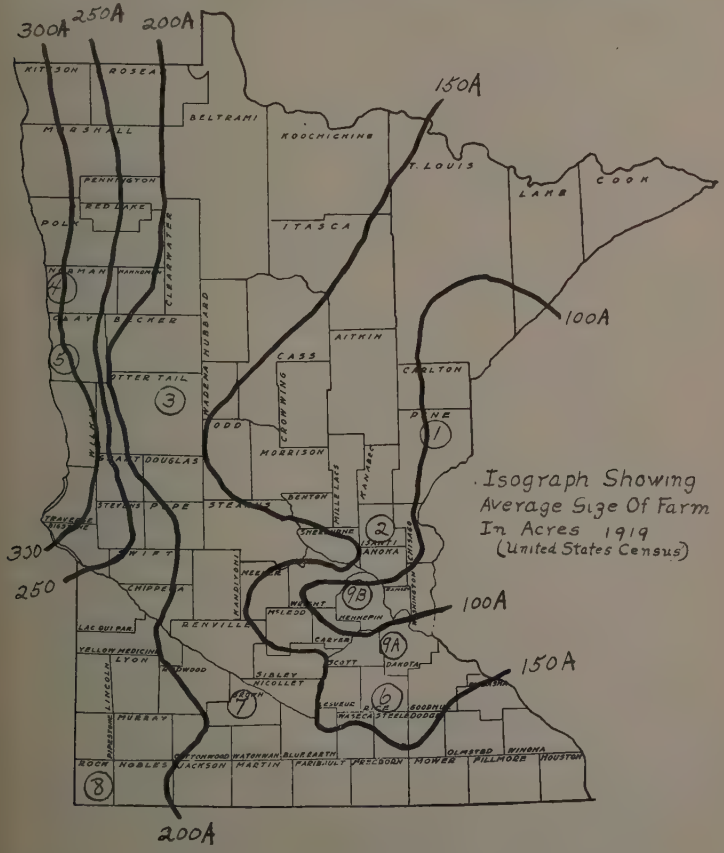


Fig. 4. Average Size of Farms

The numbered circles are the communities surveyed. Size of farms increases from the east-central to the northwest.

co-operation. A second was the level of understanding and high quality of living of the people. This is generally attributed to the training they had received in the Danish peoples' colleges and to the selective influences which brought the people to the community. The Non-Partisan League had made no headway in this community.

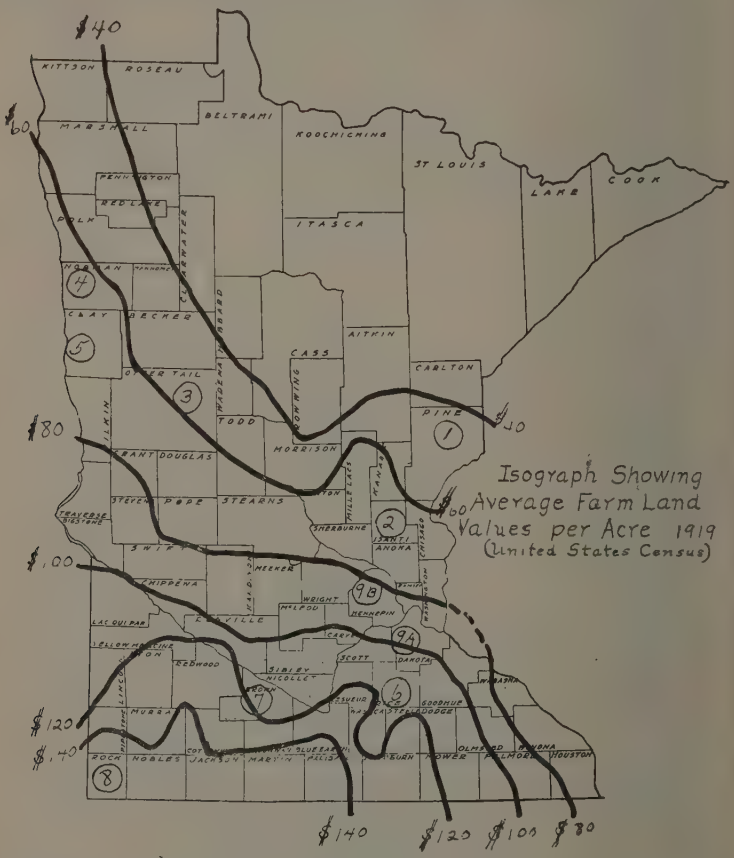


Fig. 5. Average Value per Acre of Land

The numbered circles are the communities studied. Farmers included in the study were tilling all types of soil.

The co-operatives are a creamery, a livestock shipping association, a feed store, a cow-testing association, two meat rings, and a mutual fire insurance society.[6] Many of the farmers are members of the Minnesota Egg and Poultry Association. The creamery is a member of the Minnesota Co-operative Creamery Association.[7] At one time

[6] These and the other associations named in describing these areas will be discussed later. The meat rings were consumers' clubs for co-operative butchering.

[7] Now the Land O'Lakes Creameries, Inc.

the potato growers had organized a local, which sold through the first state potato exchange when it was in operation. They later joined the second potato exchange and sold through it for the year that it lasted. Rutabagas were sold privately. The shipping association was a member of Central Co-operative Commission Company, at South St. Paul. A local buyer was handling cattle on a similar basis and selling through a private commission firm. For some years the farmers had stamped their eggs and handled them through the grocery stores; but now they were joining the state association. The feed store was 12 years old.

Cambridge, in Isanti County, is a predominantly Swedish community around a county seat village of 1100 people. It is also in the old potato belt. Much of the soil is more or less sandy. Sources of income, in order of importance in normal years, are potatoes, dairying, poultry, livestock, and small grains. The community had suffered from several years of poor crops and low potato prices. Farmers had cut their expenditures to a minimum, and the Non-Partisan League had been popular. A local paper owned on the League plan had been a financial success. Farms averaged 124 acres. Less than 20 per cent of them were farmed by tenants. The foreign-born comprised 37 per cent of the population. All of these were of Swedish descent, but had lived in the United States an average of 33 years.

The co-operatives consisted of a creamery and a livestock shipping association. Many of the growers had been members of a local of the old potato exchange. This is an important potato market, having 15 warehouses. The recent development of the new potato belt in the Red River Valley has been somewhat at the expense of potato growing in this area.

Competition between creameries in this territory was very ruthless at the time of the survey. Some of the farmers were being solicited daily by representatives of three creameries. This competition had led to faulty business practices and some failures. The local creamery was being reorganized on account of losses sustained a few years before. The livestock shipping association had recently been reorganized because of dissatisfaction with declining receipts. Poultry and small grains were handled privately, altho there was talk of a poultry local.

New York Mills, in Ottertail County, is a Finnish village of 500 people located in the center of a large area populated by about 15,000 Finnish people, about 3000 of whom are tributary to this village. It is on the western edge of the cut-over territory of the north central part of the state. The first Finnish people settled about 1875 as employees in the logging industry. Sources of income are dairy products, small grain, livestock, potatoes, and poultry in order named. Potato growing had been developing rapidly of late.

The community is divided into two groups on the basis of social and political philosophy, and these groups had taken issue on various economic problems. One group publishes a weekly newspaper in Finnish, which is the language most commonly spoken. The other group consists of the more conservative element. Of the sample taken, 45 per cent were foreign-born. The average time of residence of the foreign-born was 32 years. This is, therefore, one of the oldest Finnish communities of the state. The average size of the farms was 165 acres, and 16 per cent of the farmers were tenants. The Non-Partisan League had been very popular, especially with one of the groups mentioned.

The co-operatives consist of a creamery, an elevator, a feed and flour mill, two shipping associations, a consumers' store, and a farmers' telephone. Some of the farmers were members in the new potato exchange. The creamery is a member of the Land O'Lakes Association. The community was much divided at the time over the question of the best location for a new plant. The elevator, organized in 1913, had paid patronage dividends every year except 1923. In that year, it did a small volume of business on account of a drouth. Prices for grain declined during the year. The mill was organized in 1919 to grind local grain into flour and feed. It has been recapitalized once, partly because of small crops and falling prices. About two-thirds of the stockholders in the elevator were also interested in the mill. There was some talk of a combination of the two to reduce overhead expenses. One of the shipping associations did business with the Central and the other with private firms. They ship on alternate weeks, the Central getting the majority of the business. Eggs were handled co-operatively through the store. This store, established in 1911, paid patronage dividends every year until 1920 when there was a drop in prices. It was recuperating slowly. The telephone exchange and a local bank had recently been reorganized on account of losses.

Ada, in Norman County, is a county seat village of 2000 people in the Red River Valley. The village began as a sawmill town about 1880, but the lumber, floated down the river from the forests to the east, has long disappeared, and agriculture is now well developed. Sources of income, in order of importance, are wheat and other small grains, dairying, potatoes, livestock, and sugar beets. Potatoes and sugar beets had been introduced recently, as a result of crop adjustments in the valley. Rust and thistles had created a demand for cultivated crops, and low prices for wheat made diversification desirable. The dairy industry had been established on the lighter soils to the east of town for a long time, but had only recently spread to the west of the village.

The sample included mostly the farmers on the heavier soils to the west, it being desired to include small-grain farmers principally. The average size of farms was 341 acres, and 31 per cent of the operators were tenants. The foreign-born comprised 23 per cent of the total. Norwegians were most numerous, with Germans and Canadians tying for second place. The foreign-born had resided in the United States an average of 38 years. The Non-Partisan League had been fairly popular in the area.

The co-operatives were two grain elevators, a creamery, a livestock shipping association, and a local potato warehouse. A number of the farmers had memberships in the new potato exchange and in the Minnesota Wheat Growers' Exchange. The two co-operative elevators—one a local farmers' elevator and the other a branch of the Equity—were closed. The farmers' elevator, which had operated during the last five years, had lost money each year. The Equity had closed when the central organization went into receivership, eighteen months before the study was made. The trouble with the elevators was no doubt partly the low and declining prices for grain, but partly also the steady decline in the acreage of small grains in the valley. The first creamery, organized in 1888, had failed. The present creamery was started in 1903, and reorganized in 1915. It is a member of the state poultry exchange and eggs are handled as a side line. The livestock shipping association was organized in 1917. Since then it has gone through two cycles of growth and decay. It grows when the farmers are dissatisfied with the margins taken by the local buyers, and decays when the buyers cut margins to meet or underbid the co-operative. More farmers were members of the potato exchange than of the wheat exchange. The members of the wheat exchange had sold only one crop through it. The potato warehouse was being used for storage only.

Moorhead, in Clay County, is a mixed community, a city of 6000 located on the state line in the southern portion of the Red River Valley. Fargo, North Dakota, a city of 22,000, is just across the river. The farms studied made a half circle around the city on the Minnesota side of the state line. Sources of income, in order of importance, were wheat and other small grains, and potatoes, with beef cattle and dairying taking small third and fourth places, respectively. As at Ada, some sugar beets were being grown. This is a community of large farms, the average of those studied being 398 acres. The valley at this place is as level as a table and apparently very fertile. The same change to diversification is going on here as at Ada. The large farmers had many of the characteristics of city business men, some of

them selling their crops personally in the Twin Cities. The Non-Partisan League had been popular in the county, but not in this community. Only 22.5 per cent of the sample were tenants. A fourth of the sample were foreign-born, mostly Swedes and Norwegians. The average time of residence for the foreign-born was 33 years. The Norwegians predominated in the first generation of native-born.

The community as a whole had very little knowledge of co-operation and was markedly indifferent toward it. There was only one co-operative in operation, a local potato commission company organized in 1913. However, a number of farmers had memberships in the new potato exchange. The exchange had a large storage warehouse in town. Three other types of co-operatives had been tried here and in the surrounding country, namely, creameries, livestock shipping, and farmers' elevators; but all had failed.

Faribault, in Rice County, is a county seat town of 11,000 population in the southeast dairy section. Sources of income in order of importance are dairying, hogs, poultry products, and minor crops. Dairying is of outstanding importance. The annual butterfat production of this section of the state is estimated at about 4000 pounds per square mile.[8] Farms averaged 135 acres in size. About a fourth of them were operated by tenants. A third of the farmers were foreign-born, mostly Hollanders and Germans. French were numerous in the first generation of native-born. The average number of years of residence for the foreign-born was 34. Diverse nationalities appeared to have hindered economic and social co-operation in the community. The Non-Partisan League had never been popular.

The co-operatives in the area are two creameries, a livestock shipping association, and an egg and poultry association. At one time there was a farmers' elevator in town, but it passed into private hands. A co-operative store failed in 1912. Formerly the community shipped milk to the Twin Cities, but with the gradual development of more intensive dairy production nearer the market, Faribault dropped out of the Twin City milk supply area. A private condensery and a co-operative creamery were then started. The creamery failed in 1917, but another was started at once and is operating successfully. The second creamery, started in 1921, is the larger of the two. In 1923 the two creameries made three-quarters of a million pounds of butter. The livestock shipping association was organized in 1917. For the year 1923, it did $600,000 of business. In 1924, a small packer from southern Minnesota established a buyer in the area who offered prices higher than those on the St. Paul market minus freight from Faribault. This caused some disloyalty, and the loyal members were

[8] Minn. Tech. Bull. 26, p. 9. (No longer available for distribution.)

agitating for reorganization on a contract basis. The egg and poultry association is a charter member of the central organization.

Sleepy Eye, in Brown County, is in a second-generation German community—a village of 2000 people in the mixed-farming territory in south central Minnesota. Sources of income, in order of importance, are hogs, dairying, beef, poultry, and corn. The post-war decline had placed dairying temporarily on a par with hog raising. Local opinion was divided as to the permanency of this situation. The average size of farm was 215 acres, and 23 per cent of those studied were tenants. Only 14 per cent were foreign-born. At one time the Non-Partisan League was very popular in the community. The sample taken was not so large as in the other communities, owing to conflict with the haying season.

The co-operatives consist of a livestock shipping association, a creamery, an elevator, and an informal wool pool. There had been some agitation for an egg and poultry association, but it had not materialized. The livestock association was organized in 1916, and by 1924 was handling about 80 per cent of the local shipments. The creamery was established in 1916 by moving a smaller open-country creamery to town and securing more members. By 1923 it was making 300,000 pounds of butter, about double the 1916 production. The farmers' elevator was organized in 1899, had deteriorated into a stock company, and in 1921 was reorganized on co-operative lines. It handles bulk farm supplies as a side line. The informal wool pool, begun in 1920, was handling about 10,000 pounds of wool a year.

Luverne is a county seat town of 2800 in the choice corn-belt section of extreme southwestern Minnesota. In order of importance, incomes are derived from hogs, beef, dairy products, corn, and poultry. Hogs and beef are by far the outstanding sources of income. Corn, the principal crop, is nearly all fed locally. Dairying has gained on beef production since the war, but this may not be permanent. The farms averaged 224 acres, and 30 per cent were operated by tenants. The foreign-born comprised 23 per cent of the population and were mainly Germans. The so-called "Yankees" were about equal in proportion with native-born sons of German immigrants. The farmers were individualistic in a true sense of individualism, that is, they bought and sold on their own judgment and were fairly successful. They knew very little about co-operation, but knowledge was developing with the growth of the shipping association. The only co-operative in the community was a livestock shipping association. At one time a farmers' elevator was established, but it had gradually gone into private hands. About 1909 a co-operative creamery was started, but it soon failed. At the time of the study, there were only

two co-operative creameries in the entire county. The livestock shipping association, organized in 1920, ships to Sioux City, Iowa, where it is a member of a central co-operative commission firm. Most of the large farmers ship to the market on their own account, and the association gets most of its business from the "less than carlot" producers.

The Twin Cities Milk Territory consists, roughly, of the farming territory within a radius of 40 miles about the Twin Cities. Within this territory, 6203 farmers belonged to the Twin City Milk Producers' Association on September 30, 1924.[9] The association had 14 plants for handling milk, and 50 locals for communication with the members. Half of the sample was taken north of Minneapolis, around Osseo and Robbinsdale, in Hennepin County, and the other half south of St. Paul, around Farmington and Rosemont, in Dakota County. The farmers produce milk and truck for the Twin Cities and do a little general farming as a side line. The sample was biased to include mainly milk producers, because the truckers had had very little experience with co-operation. The average farm was 124 acres. The smaller ones were near the cities and the larger ones farther away. More than a fourth of the farmers were tenants, and 30 per cent were foreign-born. The majority of the foreign-born were Germans, Danes, and Swedes. They had resided in the United States an average of 37 years. The farmers in this territory were above the average in intelligence, which may be due either to the selective influence of the city, or to the greater number of social contacts, or both.

MARKETING INSTITUTIONS

Before proceeding further with the study, it will be necessary to discuss a few of the marketing organizations of the state. Those for marketing dairy products consist of local creameries, centralizer creameries with their cream stations, The Minnesota Co-operative Creameries, Inc. (now called the Land O'Lakes Creameries, Inc.), and the Twin City Milk Producers' Association. In 1924 there were 647 co-operative creameries compared with 124 proprietary and 46 centralizer organizations. The co-operatives comprised four-fifths of the number of organizations and made two-thirds of the butter. The centralizers, however, have stations in many cities and villages which buy cream and ship it to their factories. Land O'Lakes Creameries, Inc., is a federated non-profit service and sales organization having a membership of 430 local co-operative creameries in 1926, of which 20 were located in Wisconsin. Thus, about 63 per cent of the local co-operatives in Minnesota are members. The study included 246 farmers selling

[9] Secretary's Annual Report for 1924.

through co-operatives, 41 through proprietary creameries, 32 through centralizers, and 32 who either produced no butterfat or made butter at home. The nine communities studied had 7 co-operative, 7 proprietary, and 22 centralizer cream stations. The Twin City Milk Producers' Association is a bargaining organization which deals with the distributors. It was organized in 1916 and its members now produce over three-fourths of the milk consumed in Minneapolis and St. Paul.

The livestock marketing organizations include local shipping associations; local buyers; the central market organizations, including the commission firms at South St. Paul; the stockyards corporation; the Central Co-operative Commission Company; the Farmers' Union Livestock Commission Company, and the packers. There were 577 local livestock shipping associations in the state in 1926. The Central Co-operative Commission Company was organized in 1921 and by August 1, 1924, had a membership of 618 locals. The Farmers' Union Company was organized in 1922 as a successor to the Equity Co-operative Exchange. The Central handled about 27 per cent of the entire sales at South St. Paul in 1924. The Farmers' Union Company is much smaller. There are about 28 private commission firms in the South St. Paul market. Of the 345 farmers studied, 216 were members of one of the eight shipping associations in the communities. These eight shipping associations handled 1072 cars of livestock in 1923. Four of the locals shipped all cars to the co-operative commission companies, one shipped to a private commission firm, and three to both types.

The grain marketing agencies are the local elevators, the Minnesota Wheat Growers' Association, the Minneapolis Chamber of Commerce, and the flour mills. By 1924, there were 413 farmers' elevators in the state, which handled 48 per cent of all grain marketed at country points.[10] The Minnesota Wheat Growers' Association is a centralized contractual organization operating with a so-called "standard marketing agreement." The 1923-24 crop was the first handled. Of the 345 farmers, only 94 were members of farmers' elevators, and only 24 of the Minnesota Wheat Growers' Association.

Local co-operative potato marketing began about 1908 and grew slowly until 1919, at which time it expanded rapidly, owing to the decline in prices. The first potato exchange was formed in 1920 by the federation of 92 locals. It ceased operation after three seasons. Its failure is generally attributed to declining prices, lack of co-ordination, and inefficient management. It was succeeded in 1924 by the new

[10] Minn. Agr. Exp. Sta. Bull. 224, p. 6.

exchange, which was a centralized organization rather than a federation. The new exchange handled 10,000 cars the first year, but disbanded before the next season. This study was made just before the new exchange began operation. Of the farmers included in this study, altho 225 produced potatoes for sale, only 50 had been members of locals, only 36 had sold through the old exchange, and only 80 were members of the new one.

Poultry and eggs have nearly always been handled in Minnesota as side lines of the grocery business. Produce houses developed later in communities with sufficient volume of business. The cream stations of the centralizers also began to purchase eggs. The first co-operative selling of importance was as a side line of the local creameries or farmers' stores, or elevators. In 1923, various local or district units began organizing with a view to combining later into a central exchange. The central exchange began operating in May, 1924, under the name of the Minnesota Egg and Poultry Association. In 1926 the name was changed to the Lake Region Egg and Poultry Exchange. This study included 21 members of the exchange, and a number of others who were handling their eggs and poultry through other co-operative agencies.

Table II contains a summary of the experience which the 345 farmers had had with these various co-operative organizations up to the time of the survey. They had held or were holding 257 memberships in creameries, 216 in livestock shipping associations, 118 in grain organizations, 135 in potato or produce exchanges, and 84 in other associations. The total was 810 memberships, or more than two per farmer.

TABLE II

SUMMARY OF MEMBERSHIPS THAT FARMERS HELD OR HAD HELD IN CO-OPERATIVE MARKETING ORGANIZATIONS

Community	Farmers surveyed	Creameries	Livestock shipping associations	Farmers' grain organizations*	Potato and produce exchanges	Other organizations†	Total memberships	Memberships per farmer
Askov	41	41	39	..	33	41	154	3.8
Cambridge	41	33	27	..	31	..	91	2.2
New York Mills	38	34	34	48	15	22	153	4.0
Ada	43	39	24	36	24	..	123	2.9
Moorhead	40	3	..	10	4	..	37	0.9
Faribault	46	42	44	..	..	11	97	2.1
Sleepy Eye	22	21	22	18	..	..	61	2.8
Luverne	30	1	26	6	..	..	33	1.1
Twin Cities Milk Territory	44	43‡	..	..	8	10	61	1.4
Total	345	257	216	118	135	84	810	2.3
Percentage of total		31.8	26.6	14.6	16.6	10.4	100	

* Includes all farmer-owned agencies for selling grain.

† An egg and poultry association, some co-operative purchasing agencies, and others.

‡ Twin City Milk Producers' Association.

WHAT FARMERS BELIEVE AND KNOW ABOUT CO-OPERATIVE MARKETING AND ITS PROBLEMS

We are now ready to discuss the attitudes of these 345 farmers. Let us first consider their attitudes toward co-operation and its problems. The first part of the discussion under this head will consist merely of a description of attitudes. Later an attempt will be made to give reasons for the differences in attitudes.

It was realized at the beginning of the study that many of the farmers to be interviewed would have to be classified as having "no attitude" on many of the subjects named. An attitude is significant in proportion to the pronouncedness of it and the amount of experience and thinking upon which it is based. What farmers believe and what they know are therefore closely related. If an attitude is pronounced, it is significant, even tho it is based on limited experience or wholly inadequate knowledge of the issue in question. If it is based on extended experience or information, it is significant even tho it be somewhat indefinite and uncertain. If it is pronounced and at the same time based on extended experience and knowledge and thinking, it is most significant of all.

As was expected, many of the farmers interviewed had had so little experience with some of the problems considered, or had so little knowledge or understanding of them, that they really had no attitude, or any which they stated had little significance. In the tables and other summaries, therefore, a group of farmers is frequently reported as having no attitude at all. This usually means that their experience or knowledge was too limited to furnish a basis for an attitude. In some cases, however, it means plenty of experience, but a neutral attitude.

Table III reports the percentage of the farmers interviewed who were classified as having no opinions on the various problems considered. The high percentage for stock vs. non-stock organizations, for form of organization and local vs. central control of grading and selling, and for length of contract, reflect the fact that these questions had been raised only a few years previously in Minnesota. Minnesota co-operation had nearly all been of the stock type, and the farmers of the state had little knowledge of the non-stock type. Membership contracts had been used very little. The co-operative organizations were nearly all of the local or federated type. Attitudes for or against a centralized type of organization were probably not very significant when expressed, being based largely on opinions derived from recent propa-

ganda[11] and seldom upon real information or experience. Lack of attitude toward co-operative buying was principally due to lack of experience.

TABLE III

PROBLEMS OF CO-OPERATION RANKED ACCORDING TO PERCENTAGES OF FARMERS WITH NO ATTITUDES

Problem of co-operation	Percentage with no attitudes
Stock vs. non-stock types of organization	35.0
Advertising	19.7
Control of grading and grade standards	19.1
Control of sales policy	19.1
Control of manager	18.5
Type of co-operation—localized, federated, or centralized	16.8
Co-operative buying	15.9
Length of contract	15.7
Price policy ("fair price")	15.6
Pooling vs. cash payments	11.6
Use of membership contracts	8.4
Central control of quality of production	7.3
Central control of quantity of production	7.0
Right of members to withdraw	6.4
Handling produce for non-members	5.2
Co-operative selling	0.0

It was also realized at the beginning of the work that attitudes could be defined more closely than this study provides for; for example, that instead of getting simply a "yes," "no," and "no opinion" attitude with respect to co-operative buying, that an "attitude scale" might have been used and opinions recorded of several gradations between these two extremes.[12]

In view of the type of people to be interviewed and conditions under which the interviewing would be done, it was believed best to put the responses to the questions into only the three classes mentioned. In the actual field work opinions were recorded for the most part exactly as expressed and the classifying was done later at the office.

Table IV reports the percentages of all farmers interviewed, and also of those having an attitude, who favored co-operative selling and buying and certain specific marketing practices. In the following paragraphs, the attitudes on each subject are described in detail. The percentages of those having an attitude must not be taken too literally. Some of those with no opinion were merely neutral on the subject and really should not be excluded from a percentage division.

[11] In connection with the organization of the second potato exchange, a centralized organization.

[12] See such a study by Floyd H. Allport and D. A. Hartman in the American Political Science Quarterly, Vol. XIX, No. 4, pp. 735-760, Nov. 1925.

TABLE IV

PERCENTAGES OF FARMERS WHO FAVOR CERTAIN CO-OPERATIVE MARKETING PRACTICES

Type of co-operative marketing practice	Percentage of all farmers favorable	Percentage favorable of those having an attitude
Co-operative selling	79.0	79.0
Co-operative buying	69.3	82.3
Use of membership contracts	61.4	67.0
Use of a withdrawal clause	65.2	69.6
Use of stock organization	44.4	68.3
Handling produce for non-members	58.0	61.3
Pooling	64.7	72.5
Federated organization	51.2	61.5
Central control of grading	61.8	66.8
Central control of selling	61.7	76.3
Local control of manager	58.0	71.3
Central control of quantity of production	43.2	46.5
Central control of quality of production	76.2	82.2
Advertising by central organization	66.1	82.2
Supply and demand price	41.7	49.4

Co-operating selling.—Experience with co-operative selling is so universal among Minnesota farmers that all could be classified either as favorable to it or opposed. Some had had no direct experience but had seen enough of it in operation that they had definite convictions on the subject. Some farmers with no experience favored it. A small number with only limited experience rather generally opposed it.

Co-operating buying.—The 69.3 per cent favoring co-operative buying included 61.4 per cent who favored buying through side line departments of other co-operatives, such as elevators or the creamery association, and only 15.1 per cent who favored buying through co-operative stores or other special co-operative buying agencies. Only 14.8 per cent were opposed to all forms of co-operative buying, but 69 per cent were opposed to buying through co-operative stores and the like. The 15.9 per cent with no opinion included a good many who were neutral on the subject.

Membership contracts.—The attitudes of the farmers regarding the use of membership contracts must not be taken as conclusive. They reflect in large measure the effect of a great deal of recent agitation in favor of them. It is significant that 30.2 per cent of those interviewed were still opposed in spite of this agitation. Those with no opinion were only 8.4 per cent of the total, and consisted for the most part of those who had not heard the matter discussed.

Of the 345, 65.3 per cent favored some method of terminating the agreement at the wishes of the member—53.7 per cent withdrawal at any time, and 11.6 per cent withdrawal at specified periods, such as once or twice a year. It is significant that of the 212 who favored the

use of membership contracts, 51.9 per cent, or more than half, favored the right of withdrawal at least once during a season. This indicates that they had been doing some thinking as well as listening to propaganda.

Length of contracts.—The opinions of the 212 favoring membership contracts may be classified as follows in the matter of length of contracts:

Percentage favoring a contract of less than five years	25.9
Percentage favoring a contract of five years	27.2
Percentage favoring a contract of more than five years	16.1
Percentage favoring variations in length of contract	5.2
Percentage with no opinion as to length of contract	25.6

Most of the agitation had been in favor of the longer contracts, five years or more being the period usually named.

Stock vs. non-stock form of organization.—Table IV shows that 68.3 per cent of those having any opinion on the subject favored the stock form. This is to be compared with the 38.5 per cent of those who favored the non-stock type. Nearly 7 per cent of these favored using both types, according to circumstances. The question involved in this case is somewhat technical, and relatively few of the farmers really understood the issues involved. Under the circumstances, they were inclined to favor what they knew about. Farmers with a great deal of co-operative experience often had no opinion on this matter.

Non-members.—The local co-operatives in Minnesota have nearly all done business with non-members. They had been told recently by many people, that this is wrong. That 36.8 per cent were opposed to it, indicates that the agitation had had some effect. It should be added, however, that many farmers have always insisted that granting membership privileges to non-members was unfair. Two thirds of those who favored business with non-members thought that there should be a differential in both price and treatment between members and non-members, while the other third favored equal terms.

Pooling vs. cash payments.—The chief difference between these two business practices is that in one the farmers receive all their money at time of delivery, while in the other a part or all of the money is held until the product is sold and not until then do they know what the price will be. Pooling was favored by 58 per cent, all cash payments by 23.7 per cent, and both types of payments by 6.7 per cent. The remaining 11.6 per cent had no opinion on the subject. This was a problem with which the farmers had had considerable experience and practically all had definite ideas about it.

Types of co-operation.—The three main types of co-operation considered were called the localized, the federated, and the centralized. The local type consists of independent units, each covering a small rural community, these units for the most part rendering the same marketing services as the small town town proprietary business units. The federated type consists of a central organization imposed upon a group of such locals. The farmers owe their allegiance to the locals, and the locals to the central organization. Any one local may fail without affecting the federation to any great extent; and, on the other hand, the economies of any one local organization or of an advantageous location are retained generally by that local. The centralized type of co-operation consists of a large group of members attached directly to the central office. The central office sets up receiving plants wherever necessary. A great deal of local autonomy is eliminated and all failures or economies react on the whole organization or at least upon other members in the same district.[13]

Merely localized co-operation was favored by 11.6 per cent of the farmers studied, federated by 51.2 per cent, and centralized by 11.9 per cent. Those having no opinion composed 16.8 per cent. Some favored different types for different commodities. Many of those who favored the federated or centralized types were not sure that they understood the differences between the two. Most of the experience of Minnesota farmers has been with the localized and federated types. Only the wheat growers' association and the second potato exchange were centralized, and these were recent developments. There had been much discussion of late in favor of centralized co-operation, but the issues involved are so large and so numerous that most of the farmers interviewed were not ready to commit themselves in favor of it.

Control of grading and grade standards.—This is connected intimately with the problem of type of co-operation. That local responsibility for grading was favored by only 15.9 per cent, as compared with 61.8 per cent for central responsibility and 3.2 per cent for joint responsibility, indicates that in this detail of practice their minds run toward centralization. Nearly a fourth (19.1 per cent) had no opinion.

Control of selling and sales policy.—Their attitudes on this point were divided almost identically with those toward control of grading and grade standards. Farmers seem to feel that the same organization which controls grading should control selling.

Control of the manager of the local.—Local responsibility was favored by 58 per cent, central by 20 per cent, and both by 3.5 per

[13] Minn. Exp. Sta. Bull. 211 discusses these types of co-operation more fully. (The bulletin is no longer available for distribution.)

cent; 18.5 per cent had no opinion. Farmers like to control the co-operative employees in the local market because they think most of the success or failure is due to these men. The proper relationship between the local employees and the members is often the keynote to successful co-operation. In this important particular, therefore, the minds of the farmers interviewed incline away from centralization.

Control of quantity and quality of product.—This is another problem of co-operation in which either the local or the central may take the major responsibility. As to control of acreage by the central, 43.2 per cent favored it and 49.8 per cent opposed it. It is safe to say that a constantly increasing percentage of the farmers of Minnesota are becoming reconciled to it. In 1924, the idea was rather new to many of them. Many more of them were at that time reconciled to the idea of central control of quality.

The inconsistencies in the farmers' attitudes on these four controls indicate that they either had not, in 1924, assimilated to any great extent the essential differences between centralized, federated, and localized marketing, or else that they really favored neither one type nor the other, but instead an intermediate type with some of the controls highly localized and some highly centralized, with all gradations between. Probably one explanation fits part of the farmers, and the other the rest.

Advertising by co-operatives.—Most of the farmers had heard reports of the experience of the California co-operatives in attempting to create demand for their products by national advertising. Of the 345, 66.1 per cent favored some kind of advertising, 14.2 per cent opposed it, and 19.7 per cent had no opinion. The advertising of dairy products was favored by 46 per cent, of poultry products by 40 per cent, of potatoes by 37 per cent, of all products by 14 per cent. Their opinions on this point represent largely an uncritical acceptance of reports read in newspapers, heard from promoters, and the like. One could not expect them to be in a position to analyze such reports.

What is a fair price?—Probably the strongest motive for co-operation is dissatisfaction with prevailing prices. In times of declining prices farmers are especially prone to try co-operation. Each of the 345 was asked what he considered a fair price, and as to the basis of price determination which he thought a co-operative should try to establish in the market. These answers are analyzed in Table V. A supply and demand concept was held by 41.7 per cent, and a cost of production concept by 33.3 per cent. About 12 per cent thought that sales prices should be proportional to the costs of things the farmers customarily purchase. Actually, there is a close correspondence

between this and the cost of production concept, but the farmers themselves did not realize this. About 16 per cent had no opinion. The table shows great variations between communities. The farmers at Askov and Moorhead had a supply and demand concept in more than two thirds of the cases, and those at Faribault and Sleepy Eye in less than one third. A part of this variation is accounted for by co-operative experience, as will be shown later, and another part by such community factors as education and traditional background.

TABLE V

SUMMARY OF ATTITUDES ON "FAIR PRICE"

Communities	Farmers surveyed	Supply and demand	Cost of production	Price level of products farmers purchase	No attitude
Askov	41	68.3	7.3	4.9	19.5
Cambridge	41	39.0	31.7	7.3	22.0
New York Mills	38	44.7	44.7	2.6	0.9
Ada	43	39.5	39.5	4.6	18.6
Moorhead	40	60.0	27.5	10.0	10.0
Faribault	46	15.2	26.1	30.4	28.3
Sleepy Eye	22	27.3	54.6	22.7	4.5
Luverne	30	33.3	43.3	23.3	10.0
Milk Territory	44	43.2	38.6	6.8	11.4
Total*	345	41.7	33.3	11.9	15.6

* This row totals 102.5 per cent because some of the farmers said that two factors should control price.

Summary and interpretations.—It appears from the foregoing that farmers are most definitely decided on the phases of co-operation which involve either class consciousness or membership relations in the local community. They are least decided on problems which are technical and theoretical in their nature and which involve relationships outside their local communities; and are most decided on problems of human nature. The main experience of Minnesota farmers has been with the stock forms of organization. This is a technical matter, therefore farmers in general have no pronounced convictions with respect to this problem.

It also appears that failures of co-operatives and other farmers' organizations have a confusing effect on their attitudes. They are convinced by some co-operative leader that a particular form of organization or business practice will insure success; and when it fails to do so, they lose all their definite convictions for the time being.

The table shows that anywhere from a tenth to a third of the farmers interviewed had no definite attitudes on most co-operative problems. If allowance be made for the upward bias of the sample, it may be said that the lower third of the farm population has no definite ideas concerning most of the problems of co-operation. Closer analysis of the data would show that only a half of this lower third of the farm population is connected with various marketing associations.

The obvious conclusions from this are that co-operative marketing practice must either be made so simple that it is within the comprehension of this lower group, or the need for harmony within the organization will require that they be fitted for membership by educating them, or that they be eliminated by the selection of membership on a basis that excludes them.

RELATION BETWEEN ATTITUDES AND CO-OPERATIVE EXPERIENCE

Table VI groups the farmers interviewed according to co-operative experience and shows how the percentage having a favorable attitude toward co-operative selling increases rapidly with co-operative experience. Figure 6 shows this relationship graphically and in more detail. From this figure it appears that the first few years of experience are the period of conversion, during which there is a rapid increase of

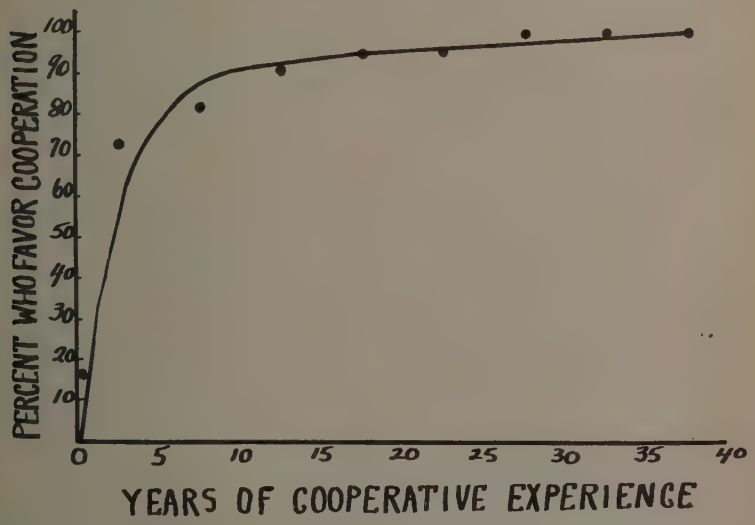


Fig. 6. Correlation Between Co-operative Experience and Attitudes Toward Co-operation

favorable attitudes. No doubt much of the early experience in many cases is with new co-operatives, many of which are always failures. Following this period of conversion, there is a long period of growth of knowledge and a gradual increase in attitudes favorable to co-operation. The great significance of this table is apparent. Given experience enough, everybody comes to favor co-operation. The majority acquire a favorable attitude quickly; a small percentage very slowly. These conclusions are highly valid, even conceding the obvious

fact that the reason why many of these farmers had had so much co-operative experience was that they were favorable toward it before they got their experience. If their experience had been disillusioning, they would no longer be favorable. Co-operative experience is selective as well as educational.

TABLE VI

Relationship Between Co-operative Experience and Attitudes Favoring Co-operative Selling*

Amount of experience	No. in group	Percentage favoring co-operative selling
None	32	16
1- 5 years	96	73
6-10 "	67	82
11-15 "	54	91
16-20 "	19	95
21-25 "	19	95
26-30 "	18	100
31-35 "	13	100
More than 35 years	27	100
All	345	79

* The Pearsonian coefficient of simple linear correlation for these data is +.66, (standard error, .09). If allowance is made for the curvilinear nature of the relationship, the coefficient is raised well over +.90. These coefficients are probably all considerably higher than true coefficients would be because some of the remaining influences average out within each group. No other method was available for correlating "yes" and "no" answers with experience. The two coefficients are surely significant enough to justify the use of the curved "regression" line in Figure 6.

What determines co-operative experience.—Since experience with co-operation is all that is needed to make farmers approve of it—with most of them only a little experience—obviously the real determinant of attitudes for any farm population group is whether or not it has had co-operative experience, and if so, how much. Accordingly, an effort was made to discover what determines co-operative experience. Data are from a study of 157 Minnesota farmers made in 1925-26. Age of farmers, income, and education were correlated with co-operative experience separately and in combination. No significant relationship was found. There appeared only a slight tendency for co-operative experience to be greater with age, income, and education. The farmers with incomes over $5000, and also those over 60 years of age, were mostly opposed to co-operative selling. The coefficient of multiple correlation was only +0.36, excluding the farmers over 60 years of age and with incomes over $5000. Apparently other factors—community and occupational environment, exposures to co-operative experience, and the like—are the major influences. Selection may be a factor.

TABLE VII

RELATIONSHIP BETWEEN CO-OPERATIVE EXPERIENCE AND PERCENTAGES FAVORING CERTAIN MARKETING PRACTICES

Amount of experience	No. in each group	Favoring contracts	Use of capital stock	Dealing with non-members	Pooling of returns	Federated organization	Supply-demand price	Central control of quantity of production	Central control of quality of production
		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
None	32	56	22	56	44	25	44	25	63
1- 5 years	96	53	36	49	47	47	40	36	65
6-10 "	67	70	60	58	54	58	37	39	76
11-15 "	54	63	52	69	63	56	35	53	91
16-20 "	19	42	32	63	58	47	42	53	90
21-25 "	19	74	42	53	74	63	53	47	84
26-30 "	18	67	44	50	89	55	50	50	78
31-35 "	13	77	31	54	69	54	77	23	92
36 or more	27	59	67	81	78	59	41	74	78
All	345	61	44	58	58	51	42	43	76

Co-operative experience and attitudes toward particular practices.—Table VII shows the relation between co-operative experience and the several co-operative and marketing practices studied—the percentages in each group which favor the use of contracts, capital stock organization, dealing with non-members, pooling of returns, federated organization, supply and demand price, and central control of quantity and quality of production. With the single exception of attitudes regarding capital stock organization, all the relationships are positive and somewhat significant. The highest relationship is between experience and attitudes favorable to pooling of returns. This indicates that the members have developed faith in one of the most essential features of co-operative practice. The experience in question is mostly with local pooling. The next highest relationship is between experience and attitudes favorable to central control of quantity of production. This suggests that the farmers have learned that co-operative marketing alone will not give them the prices they want. A few years of co-operative experience would ordinarily convince them on so fundamental a matter. Among those with a great deal of co-operative experience are the Danes at Askov, who had learned, even before leaving Denmark, that a processing factory works most efficiently when it is guaranteed a steady and dependable supply of raw material. It is significant that in spite of their experience, the farmers of Minnesota are still generally favorable to dealing with non-members and to the use of the federated type of organization. Co-operative experience has also apparently taught them that central control of quality of production is highly necessary. The relationships indicate a healthy state of mind toward the future of co-operation. The lack of relationship between experience and attitude toward stock or non-stock type of organization indicates the confused state of the farmers' minds on this point. Their older experience was nearly all with the share-stock form of organization. They had been told recently in many cases that it was not the proper form of organization; but their recent experience with the non-stock form of organization was not very encouraging.

Table VIII measures in Pearsonian coefficients the amount of relationship between co-operative experience and the group average of attitudes favorable to those business practices as given in Table VII. These coefficients are not to be taken as true coefficients of correlation because, as already explained for Table VI, they are based upon group averages. They are to be interpreted here merely as indexes of different degrees of relationship with co-operative experience for these several marketing practices.

The significant conclusion is that co-operation is itself one of the best educational forces for further co-operation. The co-operative mar-

keting technic of the future is developing through the experiences of the present. This growth of behavior patterns is a social process to which the revival method of co-operation can make little, if any, contribution.

TABLE VIII

CORRELATION OF CO-OPERATIVE EXPERIENCE WITH GROUP AVERAGE ATTITUDES REGARDING VARIOUS BUSINESS PRACTICES

Type of co-operative marketing practice	Gross correlation coefficient
Use of membership contracts	+0.466
Capital stock form of organization	— .015
Dealing with non-members	+ .587
Pooling of sales product	+ .907
Federated type of organization	+ .533
Supply and demand price	+ .452
Central control of quantity of production	+ .701
Central control of quality of production	+0.581

WHAT FARMERS THINK AND KNOW ABOUT MARKETING AGENCIES

We are now ready to consider the attitudes of the farmers toward specific market agencies, some co-operative and some not. These agencies include the Minnesota Co-operative Creameries, Inc., the Twin City Milk Producers' Exchange, the old and new potato exchanges, and a number of private agencies handling livestock and small grain. Following is a summary of the general current of opinion and the amount of information farmers had regarding these agencies.

The Minnesota Co-operative Creameries, Inc.—The study included 246 farmers who sold butterfat co-operatively; however, in only 197 cases was it sold through creameries which belonged to the federation. Each member of a federation creamery was asked to give his frank opinion of the central organization. Only 12 farmers, or 5.9 per cent of those who were members, had definite criticisms of the organization. Five of the 12 believed that it was an unnecessary expense. Three were opposed to anything but local co-operation. Two criticized the organization for low scoring of butter, 2 for inefficiency. One claimed that it favored non-member creameries in joint shipments, and another objected to the practice of suggesting salaries of local creamery operators. This is an exceedingly small amount of criticism for such an important organization.

Among the farmers interviewed were 29 who lived in communities where co-operative, proprietary, and centralizer creameries were in competition with each other and who did not sell to the co-operatives. The reasons given for not selling co-operatively were as follows: 10 disliked employees of the co-operative and claimed they did not get

courteous treatment; 2 said they had a relative or friend employed at the other place; 11 claimed the non-co-operatives paid the most money; 2 said the co-operative was too far away; 1 wanted cash for his cream; 1 said he was "afraid of the co-operative"; 1 said his wife controlled the sale of the cream; and 1 wished to sell low-test cream. These reasons seem to fall mostly into two equal classes, one consisting of those growing out of personal likes and dislikes and other purely social causes; and the other, those growing out of ignorance of proper methods of production which made them susceptible to propaganda by the private agencies. Only a few had legitimate reasons, such as distance from the creamery, for not delivering to the co-operative. The great bulk of the farmers were well pleased with their local co-operative creameries and the federation.

The Twin City Milk Producers Association.—The general feeling among the members of this association was that it was very successful. Criticisms were few and far between. The farmers most favorable toward it were found in the middle and upper income and intelligence classes, which produce five-sixths of the milk. Each member of this association interviewed was asked to suggest things which would improve the organization. Of 44 who made suggestions, 14 suggested retailing of the milk by the association; 7, more reliable testing; 5, a larger differential for the farmers nearest the city; and 4, more educational work toward improving the quality of the milk. Two objected to the membership contract, 2 warned against retailing milk, 2 claimed that the association handled milk for non-members, a practice to which they objected; 1 wished the older members to advance more capital, and 1 thought the differential for tainted milk was too high.

In spite of considerable educational work done among the members by the officers and managers of this association, some farmers were badly misinformed with respect to its methods and practices. They had obtained their misinformation in some cases from employees of the association. It appears highly important for co-operative associations to keep all their employees correctly informed as to methods and policies being followed. The outside public and the membership expect them to be "on the inside," when, as a matter of fact, in some associations they know less than observing outsiders. This is especially important if the associations have employees, as milk collectors, who circulate regularly among the members. It is exceedingly difficult to reach the lower stratum of the membership of an association by the usual methods employed. Farmers in this group will not read weekly or monthly news letters or association organs; they will not attend meetings. Left to themselves, they pick up mostly gossip and false reports.

Old potato exchange.—A total of 225 potato growers were included in the survey. The 36 members of the old exchange had little knowledge concerning the reasons for its failure. The failure came gradually, the locals withdrawing one by one because of dissatisfaction with the service. The members told of particular mistakes made by the exchange, as selling a certain carload of potatoes at a price below the market for that period, but they had failed to analyze its insufficiency according to the principles of co-operation. Not only was the percentage of farmers who had belonged to it very low, but a large number of them did not know that it had even existed. In the Twin Cities Milk Territory, less than 25 per cent knew that there had been a previous potato exchange, altho 81 per cent grew potatoes. The growers in this territory, however, grow early potatoes mostly and for the local market. Farmers note and remember specific things which happen to them, but not very often the incidents which occur outside of their communities or which do not affect them directly.

New potato exchange.—Of the 225 potato growers interviewed, 80 were members of the new potato exchange, about to begin operating. Each member and each non-member living in the same community was asked to give his opinion of the new organization. Of the members, 87.5 per cent gave favorable opinions and 18.8 unfavorable, some giving opinions of both sorts. It is surely highly significant that 18.8 per cent of the farmers in the survey had an unfavorable attitude to the Exchange within a few months after signing a five-year membership contract with it and before it had handled a potato. Of the non-members, 28.5 per cent were favorable, 57.6 per cent were critical, and 26.0 per cent had no opinion.

These attitudes are analyzed in Tables X and XI. It is important to remember that these tables represent opinions and attitudes obtained after the membership campaign and just before the organization began operation. Two important conclusions may be drawn from these tables. The first is that favorable attitudes in at least 50 per cent of the cases were based upon erroneous economic assumptions. Illustrations of this are the 26.7 per cent who thought great economies would arise from holding potatoes off the market, the 6.1 per cent who thought that the organization could set prices, and the 3.6 per cent who thought it could control acreage. Most opinions with respect to speculation and middlemen's profits are in considerable part unfounded. The second conclusion is that the unfavorable attitudes were founded mainly upon distrust of leadership. They objected to the management or pointed out the possibilities of graft, and mentioned the so-called "outsiders" who were aiding in the organization of the association.

TABLE X

REASONS FOR APPROVING THE SECOND MINNESOTA POTATO GROWERS' EXCHANGE, RANKED ACCORDING TO OCCURRENCE*

Rank	Content of attitude	Occurrence	Percentage of total attitudes
1	It will control selling by holding and pooling	44	26.7
2	It will cut out speculation, gambling, and middlemen's profits	25	15.2
3	It will improve the quality of the potatoes	20	12.1
4	It will establish a fair grading system	14	8.5
5	It will advertise, find markets, and merchandise	13	7.9
6	It will require everyone to stick to his contract	11	6.7
7	It will set a fair price	10	6.1
8	It will reduce costs of distribution	7	4.2
9	It will control acreage and production	6	3.6
10	It is large enough to control the markets	5	3.0
11	It will do away with the fluctuating system and stabilize the price	5	3.0
12	The other system failed and this is co-operative	4	2.4
13	It will furnish competition for the dealers	1	0.6
	Total	165†	100.0

* Taken from one to three months previous to its opening.
† Some farmers gave more than one reason.

TABLE XI

CRITICISMS OF THE SECOND MINNESOTA POTATO GROWERS' EXCHANGE RANKED ACCORDING TO OCCURRENCE*

Rank	Content of attitude	Occurrence	Percentage of total attitudes
1	The management will be crooked	24	17.7
2	The control of acreage is not provided for	20	14.7
3	The contract is too long	20	14.7
4	There will be graft, especially in purchase of warehouses	15	11.0
5	The centralized control makes it top heavy	11	8.1
6	The contract is too weak	8	5.9
7	Pooling and holding will not work	7	5.2
8	The organization is too large	7	5.2
9	The overhead costs will be too high	6	4.4
10	It is a mushroom organization formed by outsiders	5	3.7
11	Farmers need production rather than marketing economies	4	2.9
12	A perishable product can not be handled co-operatively	3	2.2
13	It is too small an organization	3	2.2
14	The home storage provision will lead to losses	1	0.7
15	It has no capital with which to operate	1	0.7
16	It is a monopoly	1	0.7
	Total	136†	100.0

* Taken from one to three months previous to its opening.
† Some farmers gave more than one criticism.

Agencies for marketing livestock.—Of the 345 farmers studied, 216 were members of livestock shipping associations and had been members an average of 5.5 years. Most of the memberships were among the less-than-carlot shippers. Seven of the associations shipped all or a part of their livestock to the Central Co-operative Commission Company. The attitudes of the members were influenced by two main

factors, (1) the importance of livestock as a sales product in the community, and (2) the feeling of antagonism which has developed toward the packers and the old line commission firms at South St. Paul. In communities where livestock is a minor source of income, and where its production was then mostly in a state of development, as in the Red River Valley, the attitudes toward co-operative shipping were not positive, and varied a great deal. When farmers in these areas became dissatisfied with the prices paid by local buyers, they turned to the association. As soon as buyers met the competition of the associations, some of the farmers deserted the association. In the short space of seven years, one association had gone through two such cycles of growth and decay. On the whole, co-operative shipping was accepted as a satisfactory method of handling livestock at the local market. In the heavier producing areas, the most common problem encountered was that of keeping members from selling to packers' representatives. This was causing the other members to favor incorporation and contractual organization.

The attitudes regarding the Central Commission Company, at South St. Paul, were a reflection largely of the existing beliefs that the old line commission companies have been unfair to farmers' organizations. Of the total number of farmers, 43.8 per cent were of the opinion that the general tendency of the South St. Paul market was to take advantage of farmers. There were 29.8 per cent who had no opinion on this subject, and 26.4 per cent who were at least not antagonistic to the private agencies in the market. The trouble which the Central Commission Company had had with the Federal Packer and Stockyards Administration had added to this feeling of antagonism, the farmers as a rule believing that the old line companies were at the bottom of this trouble.

Each farmer was asked his opinion as to who should own and who should regulate the meat packing business. Private ownership was favored by 39.3 per cent, government ownership by 29.1 per cent, and farmer ownership by 23.0 per cent. The remaining 8.6 per cent had no opinions on this point. Most of those in favor of private or farmer ownership thought government regulation was necessary. Only 15 per cent were opposed to government regulation, most of these favoring "farmer regulation" instead.

Agencies for marketing grain.—Of the farmers studied, 94 held membership in farmers' elevators, and 24 in the Minnesota Wheat Growers' Association. Others had sold through farmers' elevators but did not hold shares of stock. A characteristic of the elevators is that membership requires ordinarily a relatively large investment of capital,

and as a result shares are often not widely distributed in the communities. Many of the elevators do not limit the dividends in stock, and hence are not true co-operatives. This is coupled with concentration of ownership in a relatively few hands in many cases. The change from grain to livestock production by the farmers in some regions has reduced the membership in the elevator organization. The elevators are no longer sales agencies for the farmers' main crop. The rapid decline in prices of grain following the War caused the failure of a number of the elevators, and the practical disappearance of patronage dividends from the others. For these and no doubt other reasons, the farmers of Minnesota, so far as covered in the survey, did not seem to be greatly interested in their elevators in 1924. There were no definite trends of opinion concerning them. Most of the farmers were not even thinking about them.

The 24 members of the Minnesota Wheat Growers' Association had had very little experience with it. Fifteen had delivered one crop, 7 had delivered no crop since signing, 1 had had a crop failure, and 1 had broken his contract. Of the 15 who had delivered their 1923-24 crop to the association, 1 reported satisfaction, another claimed that he had lost 5 cents per bushel, and the other 13 were very anxiously and somewhat skeptically awaiting their last payment. The outstanding fact was the members' complete lack of information concerning the association, and, in consequence, their eagerness for information or even rumors.

The farmers in all but one community were asked to give their opinions concerning the Minneapolis Chamber of Commerce, the practice of trading in grain futures, and the ownership and regulation of the flour mills. Of the 297 farmers interviewed, 59 per cent thought that the Minneapolis Chamber of Commerce was harmful to the interests of the farmers, 14.8 thought that it was favorable, and 27.2 per cent had no opinion. Future trading was opposed by 66.3 per cent, and favored by 16.2 per cent. The other 17.5 per cent had no attitude. Private ownership of the flour mills was favored by 38.1 per cent, government ownership by 25.9 per cent, and farmer ownership by 24.6 per cent. The remaining 11.8 per cent had no opinion. Government regulation was favored by 76.4 per cent, farmer regulation by 10.8, and no regulation by 2 per cent. About 11 per cent had no opinion.

Agencies for marketing poultry and eggs.—Co-operation in egg marketing began as a side line of the creameries. The need for better organization was discussed in 1923 at the annual meeting of the creamery federation. The Minnesota Co-operative Egg and Poultry Exchange was an outgrowth of this meeting. The exchange was formed

on May 3, 1924. Its organization consists of county or district locals which have contracts with their members, these locals in turn having contracts with the central organization. In most cases the contracts may be cancelled once a year during certain seasons. Twenty-one members of the exchange were interviewed. At that time, there were only 13 so-called locals or county exchanges.

One of the main reasons for forming the association was the lack of a standard grading system for eggs. The wholesale dealers of the state at one time unanimously agreed to purchase only according to government grades, but the agreement was not carried out. Most of the eggs were purchased through the retail grocery stores at which the farmers trade. The grocer is primarily interested in his patronage. Buying eggs by grade often antagonized some of the patrons, so the grocers found it easier to pay an average price for all eggs, and this the wholesale dealers could not overcome.

When the association was organized it faced three problems which are of interest to this study—grading, pooling instead of cash payments, and the organization of delivery places. Farmers ordinarily recognize only two grades of eggs, plain eggs and rotten eggs. For years, poor producers had been getting the same prices as good producers except for the few that were candled out. Hence most of the members had to become adjusted to the grading idea and to readjust some of their methods of production. Most of them were used to receiving cash at time of sale. In many rural districts eggs were a principal source of cash income in the seasons between sales of the major products. The association opened with 15-day pools. This meant at least 30 days before the first check came. Market prices fluctuated between time of delivery and time of payments. Members often remembered the peak of prices during this whole period when they compared store prices with exchange prices. The new places for delivery were generally near the co-operative creameries. In a good many cases, the women deliver the cream. This meant that the buttermaker had to handle the cases of eggs and crates of poultry. He was allowed a small fee for this. This creamery man thus became practically the only representative of the association with which the egg producer came in contact. Often he had no dependable information concerning the poultry organization and in many cases disliked the irksomeness of handling the produce. Sometimes the egg member became dissatisfied with returns and blamed the creamery. These details are mentioned because they indicate the psychological readjustments which the producer had to make in the early days of the organization.

Some of the locals realized the significance of these psychological adjustments and tried to help the members in the transition. Money was

secured and part cash was paid at time of delivery. The former selling places were made points of delivery and a great deal of educational work was done and personal contacts were maintained. Other exchanges, not appreciating the importance of this, suffered from some disloyalty. The former middlemen were active in inciting suspicion. They did this at times by publishing propaganda, but mainly by circulating rumors and by occasionally quoting irregular prices on eggs.

Some of the locals met this crisis by invoking Section 27 of the 1923 Co-operative Marketing Act of Minnesota, which provides for enforcing contracts with members, and also forbids third parties soliciting products under contract to co-operative marketing associations; and also by the use of blanket threatening letters to the members. Following is an actual sample of one of these letters:

————County Co-operative Egg and Poultry Association,
————, Minn., July 1, 1924

Members of Association:

Some time in the past year *you** agreed with your neighbors in ———— County and adjoining counties to market *your* eggs and poultry co-operatively, in order to improve the quality, lessen the spread between the price to the producer and to the consumer, and increase the returns to the producer.

When one views impartially the markets of the Northwest, one can see that the spread has been very much narrowed. The markets near the co-operative associations are higher than those at points nearer Chicago where they formerly had the advantage. Many times the local prices have been even with those in the Twin Cities—a condition that has seldom existed before.

A few of *you* for various reasons have not lived up to *your* agreement with your neighbors. Some signed the marketing contract when they did not have any poultry products to market.

A large number of our members have enjoyed an unusually good demand for hatching eggs. This is a good thing for the community as it tends to improve the standard of the eggs and poultry we will handle. Selling for this purpose is encouraged but, of course, it cuts down our supply materially.

A few have felt that their small number of eggs would not make any difference, while a few have plainly disregarded their obligation to their neighbors who have been making the market by supporting your organization. It would make a difference of a cent or more had we had all the eggs we had a reason to expect.

Your contract is just as legal a paper as any note and is enforcible. Any dealer who buys from a member of a Co-operative Association is also liable under the New Minnesota Co-operative Law, and the directors are considering taking steps to see that this law is enforced.

It should not be necessary to do anything further than to give you our best effort to get 100 per cent co-operative. In other words, it is up to the members to see that they live up to their contract and deliver their eggs.

* Italics supplied.

> We have enlarged our membership nearly 100 per cent. We are mailing out a good return for the first half of June. Market at different points was all the way from 18 cents to 22 cents for firsts and 16 cents for seconds. We are returning 23 cents for top grade and we have some instances where members' eggs grade 80 per cent of that grade.
>
> We returned 36 cents for broilers and 28 cents for heavy hens; so you will agree we are making the market and getting consistent prices. We will load our first poultry car July 9, 10 and 11 and if you need coops let us know and the truck will take coops out to your receiving station next week. If you send in your own coops they will be returned on the next trip of the truck. The poultry market is about steady, but is somewhat lower than during the fore part of June. Let's all get behind the organization that will put our poultry products on the same high plane as Minnesota butter.
>
> ————Co. Co-operative Egg and Poultry Association,
> ————Mgr.

Note that this letter used "you" and "your" instead of "we" and "our," and that it suggests legal procedure against members and dealers. The psychological effects of such a letter on the members have repeatedly been demonstrated to be bad. A state of mind is set up which is highly contrary to the co-operative spirit. It apparently puts the matter of loyalty largely in the hands of the central office. The use of the second-person pronouns *you* and *your* strengthens this impression. The reaction of a loyal member may be stated as follows: "If the contract is legal and easy to enforce and an injunction can be secured against these dealers, as this letter says, let the central office do it and make this thing a success. If it does not succeed, the manager is to blame." The reaction of the disloyal member is even worse. A poultry and egg association can not afford to enjoin or sue a member over the few eggs his wife is selling at the store. A better procedure would be to explain the disloyalty. This is valuable for both loyal and disloyal members. Every contract breaker blames the association for his behavior. This is the psychology of rationalization. Some analysis of causes of disloyalty helps the loyal member to prevent disloyalty in others and, to some extent, the disloyal one to understand himself.

As a result of invoking Section 27, of the Co-operative law, the dealers became openly antagonistic. By combining with dealers in other products who were also opposed to co-operation, they were able to bring the clause before the Supreme Court of Minnesota for review.[14]

[14] Minnesota Wheat Growers' Co-operative Marketing Association vs. Radke, and Minnesota Wheat Growers' Co-operative Marketing Association vs. Commander Elevator Company. See "Agricultural Co-operation," issue of June 6, 1925. The Court pointed out that malicious interference by a dealer laid him open to damages, but that Section 27 went beyond this in making it an objectionable wrong for a dealer to receive produce from members when he had used no effort or made no inducement to them to break their contract.

The decision was sufficiently adverse to make it advisable for some of the co-operative associations to revise their policies and depend more on voluntary co-operation, which is undoubtedly the policy which they should have adopted at the start.

Reasons for Attitudes Toward Private Marketing Agencies

The attitudes which farm people have toward such institutions as the Minneapolis Chamber of Commerce and the meat packing companies at South St. Paul, are of great interest to many classes of people and of great significance to workers in the field of agricultural organizations. Many circumstances enter into and affect these attitudes. It will be well to refer to these briefly before analyzing the data obtained.

Geographic distance is a very important factor in determining attitudes. Farmers are fairly well acquainted with the things which happen in the local trading community. The local creameries, livestock shipping associations, potato warehouses, and farmers' elevators are within the range of almost daily contact. Even under such circumstances, suspicion, mistrust, and misunderstanding are all too prevalent. Organizations located in the Twin Cities are out of the circle of frequent contact for the great majority of farmers, and hence their aims, purposes, and functioning are greatly misunderstood, misinterpreted, and mistrusted.

The method the co-operatives have of handling the obstacle of geographic distance is to organize on a federated basis. In the minds of most of the farmers, the federation exists in the body of the local association. The federated type of organization is merely a method of placing centralized co-operative endeavor in physical contact with the members. But private marketing agencies find it hard to provide a substitute for such an organization.

Occupational or other social grouping may also be an important factor. Farmers as a group are socially separate from townsmen as a group, and especially from the middlemen group who handle their products. The mistrust and misunderstanding will be especially great if the two groups have vital relations with each other, as have farmers and middlemen. When this and geographic distance are combined, as, for instance, between Red River Valley farmers and members of the Minneapolis Chamber of Commerce, the avenues of mistrust are doubly open. Table XI, which summarizes the criticisms of the Minnesota Potato Growers' Exchange, is a good example of misunderstanding which arises when geographic distance and social grouping combine in the case of a co-operative.

Farmers have certain traditional types of beliefs which profoundly influence and determine their attitudes. Geographic distance, social groupings, occupational environment, and the conventional logic or types of reasoning prevalent among the farmers, lie back of these traditional beliefs. Examples of these beliefs are the following: "The farmer is the only producer," "The middlemen set the price," "Crop statistics enable the middlemen to take advantage of farmers," "All other groups are organized except the farmer, and he must organize to protect himself," "All other economic groups are parasites." These traditional beliefs play a large rôle in guiding the conduct of farmers when crises arise in agriculture. These traditional beliefs are no doubt in considerable part the result of certain modes of thinking which have become customary among rural peoples. The most prevalent of these are:

a. From one particular phenomenon to a general principle. A failure of one organization leads to generalizations concerning all organizations.
b. From simple analogy. For example: "Merchants have organized to price the goods they sell; consequently farmers should organize and set prices on their produce."
c. From correlation to causation. If two things occur together or following each other, one is certain to be assumed the cause of the other. If a co-operative begins operation on a rising market, the organization receives credit for the increase; and if, on the contrary, it begins with a declining market, it is so thoroly censored that it often fails.
d. From generalizations which are generally accepted but not proved. Their acceptance of the traditional beliefs mentioned illustrate this.
e. From vitalistic interpretations of natural or mechanical forces. By this is meant that a current method of thinking among farmers, as well as among most other people, is to attribute personal motives to very impersonal behavior, to blame persons for mishaps due to nature or very little under human control. If a cream test is lower than the farmer thinks it should be, in a great many cases he blames the buttermaker rather than his cows or the condition of his home separator. If prices of wheat sag, he blames it upon the middleman or the political party then in power.

These five elementary types of thinking are very prevalent among the modal groups of farmers. Any co-operative must combat them, and its success depends upon its ability to please its members in spite

of them. All the attitudes considered in this study are conditioned by these types of logic.

Farm people are inclined to allow the success or failure of other farm organizations to affect their attitudes toward any particular co-operative operating at the same time. Institutions which have been established and have operated successfully for a number of years build up pattern ideas which lead to attempts at duplication of these institutions for other commodities. Successful co-operation in one line leads to attempts at co-operation in all other lines, regardless of need for it or prospects of success. The early co-operatives were farmers' elevators. These were closely followed by creameries. These proving reasonably successful, co-operation has gradually spread since 1910 to all phases of farm life. On the other hand, there have been important failures from time to time, and these have weakened the morale of the whole movement for a time and have produced a temporary disintegration of the favorable attitudes toward similar institutions.

Table XII gives information about the investments which farmers in five of the communities have made since 1917 in co-operative ventures which have either failed or have never paid dividends.[15] Of the 20 organizations, 18 had been reorganized with a complete loss of the original capital stock or had gone out of business by July, 1924. Two were operating, but had barely managed to keep the original capital intact. The 203 farmers had made 155 investments in these organizations. Needless to say, the effect of these failures was very disturbing. The effect of such failures is more devastating to the morale of members of the centralized associations than of local or federated organizations because in the latter cases the farmers can see for themselves.

TABLE XII

NUMBER OF FARMERS IN FIVE COMMUNITIES WHO JOINED "FARMERS'" ORGANIZATIONS WHICH LATER BECAME DEFUNCT BETWEEN 1917 AND 1924

Community	No. of farmers surveyed	Farmer-owned papers	Meat packing plants	Potato warehouses	Creameries	Flour mills	Farmers elevators	Other types	Total
Cambridge	41	10*	4	15	12	..	..	3	44
Askov	41	..	1	..	..	..	..	..	1
New York Mills	38	8*	7	1	..	14	..	6	36
Moorhead	40	2	11	..	..	..	..	11	24
Ada	43	10	17	..	..	..	21	2	50
Total	203	30	40	16	12	14	21	22	155

* Of the 20 farmers' organizations, these two are the only ones which had not gone bankrupt or had not been completely reorganized up to the time of the survey.

Effect of co-operative experience.—The only data obtained which throw any particular light upon reasons for attitudes of farmers toward private marketing agencies, are those given in Table XIII. In

[15] This information concerning investments was not obtained in the other four communities.

general, those with considerable co-operative experience are more opposed to the private agencies in the central market than are those with little co-operative experience. But the relationship is not at all pronounced. The group of 25 farmers with most co-operative experience, 36 or more years, were most charitably inclined. The table suggests, if anything, a variety of points of view on this subject. No doubt a principal reason for obtaining co-operative experience in the first place was hostility toward the private central market agencies. Their experience apparently has made some of them more hostile and no doubt many of them less hostile. This is what would be expected. Some have become somewhat disillusioned by their co-operative experience. Others have become more attached to their own organization and more embittered toward its enemies.

TABLE XIII

RELATIONSHIP BETWEEN CO-OPERATIVE EXPERIENCE AND ATTITUDES REGARDING CERTAIN PRIVATE MARKETING INSTITUTIONS

Amount of experience	No. in group	Percentage antagonistic to South St. Paul livestock market	Percentage favoring private ownership of mills	Percentage favoring private ownership of packing plants
None	32	13	41	41
1- 5 years	96	47	41	45
6-10 "	67	48	31	37
11-15 "	54	50	36	39
16-20 "	19	53	37	37
21-25 "	19	42	41	42
26-30 "	18	33	18	22
31-35 "	13	54	31	23
36 or more	27	44	52	44
Total	345	44	38	39

WHAT FARMERS THINK ABOUT FARMERS' ORGANIZATIONS

The Farm Bureau Federation and the Non-Partisan League are two farm organizations which have had an important influence on marketing in Minnesota. During this study, some information was obtained concerning the farmers' attitudes toward these organizations. A summary and analysis of these data follow:

The Farm Bureau Federation.—County agent work was first organized in Minnesota in 1912. Since then, with the exception of a rapid growth during the War and a decline in 1921 and 1922, it has on the whole increased in public esteem. Two of the ten counties visited during this study were first organized in 1913, two in 1914, five in 1918, and one in 1921. Three of the ten county farm bureaus were inactive at the time of the study. Of the farmers included in the study, 53 per cent had been members. The average number of years of paid membership for these 53 per cent was 3.8, varying from 2.4 to

4.8 years for the separate communities. Of the 183 farmers who were or had been members of the organization, 80.4 per cent were favorable to county agent work, 18.5 per cent were opposed, and 1.1 were indifferent. Most of the 18.5 per cent were not members of county farm bureaus at the time of the survey. Of the 162 who had never been members, 25.3 per cent favored the organization, 47.0 per cent opposed it, and 27.7 per cent had no opinion to express. Of the 345 farmers visited, 54.5 per cent favored it, 31.9 per cent opposed it, and 13.6 per cent had no opinions.

The Non-Partisan League.—This has been an important organization among Minnesota farmers during the last eight years. Table XIII shows that the organization was begun in these communities in 1916 and 1917. At one time it had 1586 paid-up members at eight of the rural postoffices included in the study. It was not deemed advisable to ask the farmers included in this study as to their relationships with the League, but a great many volunteered the information. The data in the table were obtained from the files of the League. The third column in Table XIV includes all who paid membership dues between the fall of 1921 and the date of the study. They form 24 per cent of all who originally joined. In four of the communities, strong League organizations had existed, and in the four others the organization had never been significant. Moorhead is classed with the communities in which the organization had never been strong. The 136 members given in Table XIV lived in an outer portion of the mail territory. Only one man included in the particular area studied had ever joined the League.

Motives behind Farm Bureau and League membership.—The Farm Bureau is ordinarily thought of as educational, and the League as economic and political. Indeed, in many communities the organizations were at cross purposes, some of the farmers favoring political and economic measures and others educational measures. A correlation of the total membership of the League at each mailing point with the percentage of the farmers at that place who had been or were members of the Farm Bureau Federation gave a negative coefficient of -0.315.

For a few years there was considerable discussion as to the relationships which existed between the League, the Farm Bureau, and co-operative marketing. The relationship between the League and co-operative experience may be expressed by $r = +0.577 \pm 3$ (S. E. 0.108) and between Farm Bureau strength and co-operative experience by $r = -0.382 \pm 3$ (S. E. 0.137).[16] In other words there appears a slight negative relationship between the Farm Bureau and co-operation, and

[16] Complete positive correlation would be expressed by $+1.00$; complete negative correlation by -1.00.

a positive relationship between the League and co-operation. This may be due either to members of co-operatives joining the League more freely than non-members, or to the League's promotion of co-operative enterprises. Undoubtedly it was due to both, but more largely to the latter. These coefficients are low, however. This means that many other factors were of importance in both cases. A second consideration is that of final results. In a great many cases, the educational work of the county Farm Bureaus promoted co-operation best in the long run, and in many other cases the failures of unfortunate farmers' organizations sponsored by the League harmed the co-operative movement, as shown in Table XIII.

TABLE XIV

POPULARITY OF NON-PARTISAN LEAGUE IN EIGHT COUNTIES STUDIED*

Community	Year organization work began	Total persons who get mail at this P.O. who belonged to League	Mailing list of Minnesota Leader, Sept. 1, 1924†	Percentage of all who joined who were "active" in summer of 1924
Sleepy Eye, Brown County	1916	475	112	24
New York Mills, Ottertail County	1916	351	54	15
Cambridge, Isanti County	1917	330	116	35
Ada, Norman County	1916	137	49	36
Moorhead, Clay County	1917	136	31	23
Luverne, Rock County	1917	91	13	14
Faribault, Rice County	1917	63	6	9
Askov, Pine County	1918	3	..	0
Total		1586	381	24

* These figures were obtained directly from the files of the National Non-Partisan League, by courtesy of its officers.

† Includes all paid-up until late in 1923. Since Non-Partisan League memberships were on a two-year basis, column 4 includes those who paid membership fees between the fall of 1921 and date of record. The files had not been cleared of members whose paid membership ran out in 1923, because the mailing list was valuable for campaign purposes.

Another motive behind the development of these two organizations was that of protest against bad economic conditions. The war unrest, the declining price levels of 1920 and 1921, and the crop failures experienced, caused the rise and spread of these organizations. Table XIV shows that by 1922 or 1923, less than a fourth of those who had originally joined the League still maintained their membership. Men who join organizations for such temporary motives do not stay by them very long when they fail to do the impossible. Such a motive

of protest was also behind the enormous increase in membership in the Farm Bureau Federation during the 1920 membership campaign. Table XV compares an index number of prices of farm commodities with similar indices of membership in the Farm Bureau for the 10 counties studied and for the state as a whole. The Farm Bureau received a great impetus from war patriotism during 1918. It about held its own during 1919. During 1920, prices began to decline just as the membership campaign began. During this campaign the membership in the ten counties increased from 3537 to 7714, and in the entire state from 30,516 to 53,282.[17] This large membership continued during the next year and then slumped to below the 1918 level. It has grown gradually since that time. No doubt most of those who joined in 1920 and dropped out were actuated by only temporary motives.

The same temporary motives cause many farmers to join the large centralized co-operatives during intensive membership campaigns, and the organizations suffer when the time comes for delivery of the products. Probably 25,000 members of the Tobacco Growers' Association of Virginia, North Carolina, and South Carolina broke their contracts partially or entirely during the first year.

TABLE XV

Relationship Between Prices of Farm Products and Growth of Farm Bureau Membership

Year	Index Nos. of prices of 30 farm commodities*	Index of strength of Farm Bureau in 10 counties studied†	Index of strength of Farm Bureau in the entire state‡
1917	176	100	100
1918	200	237	487
1919	209	219	570
1920	205	477	995
1921	116	451	915
1922	124	189	..
1923	135	243	..
1924	134	244	..

* Taken from the June, 1925, supplement to the "Agricultural Situation," printed by the United States Department of Agriculture. August, 1909, to July, 1914=100.

† The year 1917 is used as 100. Figures were obtained from the State Extension Service.

‡ The year 1917 is used as 100. Membership figures after 1921 were kept by the State Farm Bureau, an organization separate from the Extension Service, and can not be obtained.

Several factors may affect the attitudes of farmers toward county agent work. Americanization may be a factor in it. Education, amount of reading done by the family, or the wealth and social position of the farmer as indicative of his success at farming, may all affect the attitudes toward this work. These influences were tested out by an analysis of a small group of farmers interviewed in the Rural Living study of 157 farmers previously mentioned. The five factors mentioned

[17] These figures are taken from the annual reports of the State Extension Service.

accounted for a relatively small part of the total attitudes. "Income" and "generations in the United States" proved to be significant positive influences; and a somewhat larger percentage of the older than of the younger farmers were opposed to the work. The other significant factors would probably be experience as members of the organization, physical contact with agricultural agents and extension service men, and participation in demonstrations.[18]

ATTITUDES TOWARD NATIONAL ECONOMIC POLICY

The attitudes with respect to tariff policy are summarized in Table XVI. Tariffs for manufactured products were favored by 53.8 per cent, compared with 70.4 per cent for tariffs on farm products. Those opposed to tariffs constituted 28.6 per cent for manufactured products and 17.6 per cent for farm products. The others had no opinion. The conclusions to be drawn from this table and other information obtained may be stated as follows:

1. The majority of Minnesota farmers are protectionists. Less than a fourth of all the farmers were definitely opposed to protective tariffs.

2. The most common belief among farmers is that a tariff automatically holds up the price of a product. Most of them make no distinction between the effects of tariffs upon products produced for export and those produced for domestic markets only.

3. When the farmers became dissatisfied with relative differences in price levels, they turned to protection for agriculture rather than to less protection for manufacturing.

4. Farmers have practically no information regarding existing tariffs and their effect upon the country as a whole.

TABLE XVI

ATTITUDES WITH RESPECT TO TARIFFS

Attitude	For manufactured products	For farm products
Per cent favorable	53.8	70.4
Per cent opposed	28.6	17.6
Per cent no opinion	17.6	12.0
Total	100.0	100.0

Attitudes toward the Mellon tax plan, then being discussed, were obtained from the farmers in five of the communities. This plan was fairly well known because the Literary Digest had just completed a nation-wide poll on the subject. The plan was favored by 15.8 and opposed by 47.8 per cent. The remaining 36.4 per cent knew too little

[18] See U. S. Dept. of Agr. Bull. 1384, p. 17.

about it to have an opinion or were undecided. These returns are somewhat different from those of the Literary Digest, which found 43,245 favorable and 34,899 opposed for Minnesota.

Reasons for Attitudes Regarding Tariffs

Why do Minnesota farmers think differently with respect to this measure? It is a problem of economic theory concerning which farmers have had little experience, but have rather definite attitudes. Why do they agree substantially with the dominant political thinking on the tariff and disagree as to this scheme of tax reduction? No doubt the most important of the reasons is political leadership and propaganda. Farmers have been impressed for many years with the necessity for tariffs and the doctrine of protection. Automatically they have accepted these doctrines and today protection is one of the fundamentals of their political and economic thinking. But in spite of the most vigorous propaganda for the Mellon tax plan, they had not fallen in line with it. Perhaps they may in time. It appears, however, that there are more fundamental reasons growing out of the character of logic behind the ideas. Tariffs do raise the prices of some farm products and of many manufactured products. Such an effect is easy to believe, and fairly easy to observe. In a period of generally rising prices, as from 1895 to 1920, it was not difficult for political propagandists to torture facts in such a way as to credit tariff protection with a good many things to which it had no relation. A rise in the tariff level is generally conceded to act as a temporary stimulus to business in general. Farmers as well as other ordinary business men rarely think in terms of other than immediate effects. Further statements concerning attitudes on problems of national economic policy will have to wait for more investigation and statistical analysis. From this study it is easy to observe that the attitudes regarding these problems are determined by social and psychological as well as economic factors.

SUMMARY

This study summarizes the attitudes of a representative sample of Minnesota farmers concerning co-operative marketing, co-operative business practices, marketing institutions, the Farm Bureau, the Non-Partisan League, and some current political and economic questions. The amount of experience with co-operation of the 345 farmers taken from 9 communities varied from none to more than 40 years. The majority were favorable to co-operation of all kinds and these attitudes correlate positively with their experience. Definite attitudes on the best practices in co-operative business organizations appear to be developing from experience. The road to efficient marketing is being blazed by

these organizations. Proper principles of social organization and membership relations are also developing.

Experience with such marketing agencies as co-operative and private organizations has also led to some agreement in attitudes. Co-operative organizations founded on safe principles and proceeding according to proper methods of farm psychology have won accepted places in the minds of the farmers. The result has been a growing recognition of the significance of these institutions in Minnesota farm life and a gradual increase in the amount and percentage of business handled. Proprietary organizations, especially those located at central markets, suffer from the misunderstandings which arise from the geographic and social isolation of farmers. The revival type of centralized co-operative organization has thus far proved a failure in Minnesota when measured from the standpoint of development of proper attitudes. The two chief psychological characteristics of the members of the centralized organizations included in this study were erroneous attitudes and a distrust of leadership.

The Farm Bureau and the Non-Partisan League competed for the loyalty of Minnesota farmers. The League was economic and political, whereas the Farm Bureau, especially the local county bureaus, emphasized educational work. The League, as such, is extinct. The Farm Bureau suffered a relapse because of the 1920 membership crusade; but the fundamental educational value of its work is developing favorable attitudes among farmers. This is similar to the development of attitudes favorable to co-operation.

Ideas regarding tariffs and taxation programs are the combined result of political propaganda, rural logic, and the structure of previous experience of farmers. Minnesota farmers are primarily protectionists. The next step in rural thinking about tariffs is uncertain. Farmers do not understand the prevalent theories of the incidence of income taxes.

Some of the more fundamental conclusions relating to the essential nature of rural social psychology, may be stated as follows:

1. Rural attitudes may be put into two classes. The first and most important class includes the attitudes concerning subjects with which the farmer has had actual experience. The second class consists of attitudes toward a subject with which the farmer has had no actual experience, such as tariffs or international trade.

2. Farmers in each community so vary in their attitudes toward the same phenomenon as to give a distribution often approaching the normal frequency distribution. An illustration is the attitude regarding "fair price." Forty-two per cent favored a supply and demand price, while 45 per cent favored cost of production, and 16 per cent had no idea on the subject. If an "attitude scale" could have been devised

which had even scale divisions, the resulting distribution would no doubt have approached normal. The sample had an upward bias, so that more of those with a supply and demand concept were included than would normally be expected. Why such a range and distribution of opinion exists, is an interesting subject for speculation. Does it arise because of the newness or unsettledness of the population? Or is it to be a permanent phenomenon?

3. Communities, as well as individuals, vary in attitudes toward the same concept. The percentages favoring supply and demand as a regulator of "fair price" were as follows for the nine communities: 68, 60, 45, 43, 40, 39, 33, 27, and 15. The average was 42 per cent. Most of these variations between communities were found to correlate with various environmental controls.

4. Social life in the various communities is founded upon these biological and environmental differences. Rural organizers and organizations must take this fact into consideration.

5. Different types of behavior were attributed to the same motive. Some farmers became stronger co-operators because dealers offered them a premium for disloyalty, while others turned against the associations for the same reason.

6. Identical behavior arose because of different motives. Some farmers co-operated to improve their products, and others for such reasons as creating a monopoly, etc.

7. An important factor in attitude and behavior variation is the structure of previous experience and thinking.[19] National groups, such as Danes, Germans, Finns, Swedes, Norwegians, and Yankees, so-called, have different traditions, customs, and beliefs, which are powerful factors in guiding new behavior patterns. The same is true, altho to a lesser extent, between different types of farming and various communities within each type. It also seems to operate in individual variations within the communities, causing greater differences than would ordinarily be expected.

8. A second important factor is actual experience. Where it is possible for farmers to obtain actual experience, in the long run their attitudes will be determined almost solely by it.

9. Business conditions are a third factor promoting attitude and behavior variation. The chief result of business depressions is temporary attitudes of revolt. Farm organizations which lay their foundations only in these types of motives are almost sure to fail.

10. Geographic distance is a factor behind attitudes. The great majority of farmers get their actual experience within their retail

[19] To which the term "mental configuration" is often applied.

trade area. Organizations which seek to give farmers actual experience must exist within this area.

11. "Social distance" is a factor behind attitudes. Farmers learn from people in the same social group. Farmers prefer farmers for co-operative leaders. The co-operative leadership of the future must be developed from the farm boys of the present.

12. Extreme wealth or poverty and old age are factors affecting attitudes. Co-operation should not depend primarily on either of these three groups of people for support. On the other hand, the Agricultural Extension Service finds a greater support among the wealthy.

13. In general, farmers think and behave according to the same social principles as other people. The only important differentiating influence is the occupational environment.

14. The common belief that farmers are individualists is a fallacy. The foundation of true individualism is the ability to make the majority of one's judgments upon the merits of a question. At the most, this type of individualism can be attributed to only from 10 to 40 per cent of the farmers—the proportions varying with the communities. We have called farmers individualists because we did not understand their behavior and its motive forces. Economic conditions and local traditions founded upon their occupation and the way in which they live determine the most of rural behavior. The statement that farmers are individualists is an exclamation rather than an explanation of their behavior.

Significance of Co-operative Marketing

There are as many different co-operative philosophies as there are different types of organizers. Some of these philosophies are the result of experience and are valid, while others are the result of highly subjective speculation, are based on inadequate social theories, and have been the cause of much grief on account of ill-founded farm organizations. It would be impossible to build upon the results of the present study a complete philosophy of co-operation. It must be remembered that this study has dealt only with certain phases of the problem. But it is possible to state a few conclusions which should be useful to builders of such philosophies.

1. Wherever possible, co-operation should be a growth and not a spasm. The revivalist type of organizers ask for a large membership in a few months, or years at the most, so as to control a majority of the product from the start. While a larger membership is desirable if possible, it is far safer to start small and depend upon the advantage of economy, loyalty, and physical contact rather than enormous size. A good start on the safe side is half the game. Growth should proceed

slowly and conservatively; else the growing pains may disrupt the organization. This may even require a selection of membership at the start and careful elimination as the organization proceeds.

2. Close contact between members and the organization is highly desirable. The farmer's universe, like that of most other people, is within the area of his ordinary living relations. This means that there should be responsible locals within the retail trade area, if possible, and that the ordinary risks of business should be so localized that disloyalty comes home immediately to the member and to his neighbors. The so-called "talking locals" are a poor substitute for the responsible business type.

3. Voluntary co-operation is more likely to succeed than legal coercion. The greatest mistake in American co-operative history has been the development of this excessive legalism which has arisen since the World War. Legal contracts, legal incorporation, and other legal steps are necessary. But contracts do not make co-operation. The playing up of legal obligations is one of the surest ways to co-operative failure. More money spent in education and field service and less for the prosecuting of contract violators is the policy upon which most successful associations have been built. The mainsprings of co-operation are the psychological attitudes of the members. Excessive legalism damages these attitudes and furnishes a poor and unwieldly substitute.

4. Education in co-operation is vital to success in the long run. This education must proceed by experience. Farmers who will not be educated must be eliminated. The quality of the produce, the methods of handling it, the types of production, and the business practices must be steadily improved. Co-operatives which fail to do this are failures in themselves and will not continue long.

5. Careful consideration must be given to methods for retaining the support of members. The old phrase, "the tie that binds," must be changed to read "the ties that bind." The mechanical devices of membership contracts, shares of stock, and legal incorporation must be used to solidify the organization and insure its permanency. But more attention must be given to loyalty, which is a matter of thought and feeling and not of mechanical device.

6. The avenues for withdrawal should be left open. Co-operation can not be forced. No human institution has been made so perfect that no psychopathic personalities have attempted to disrupt it. The familiar saying among farmers that "a dissatisfied member is worse than none," is true. With proper penalties, farmers should be allowed, and in some cases forced by legal pressure, to withdraw.

7. The business of a co-operative is the business of a community. Any attempts at secrecy will ultimately cost more than the possible

gain. The membership must be informed, and this can not be achieved without informing the community as a whole.

8. Co-operatives should not be oversold at time of organization. Placing attitudes on a false basis by leading farmers to expect too much from the organization or by making untrue statements regarding competing dealers is one of the surest roads to failure.

9. The organization must be simple. As has already been pointed out, a half of the intellectually lower third of the farm population become associated with most of the co-operatives. If these are to be included, the organization must be so constructed that these members can understand all that is necessary to keep their patronage. If this group be eliminated, the organization can be made more complex. But no co-operative should expect the impossible from its members. A farmer in North Carolina delivered his tobacco to a private warehouse, sincerely believing it to be a receiving station for the association. Numerous examples of similar experiences could be given for Minnesota.

Relation to Extension Work in Marketing

There are many problems connected with extension work in marketing which do not come within the field of this study. We shall deal primarily with two questions: Should the extension workers be responsible for the inspiration, organization, and success of a co-operative? What principles of organization should be used in extension work with co-operatives?

The answer to the first question is "No." None but farmers themselves can be responsible for the inspiration and success of a co-operative. The extension organization can merely act in an advisory capacity, giving judgments as to the necessity for organization, the type needed, its function, and the economies it might achieve. Acting in such a capacity, extension organizations may prevent some ill-founded organizations and some overselling of organizations.

Extension work with co-operatives is of three kinds: That seeking to improve the type of organization, such as securing the incorporation of organizations previously operating on a partnership basis; that dealing with business methods, such as securing improved accounting, prorating, or insuring against risks; and that dealing with production, such as promoting the use of certified seed in a community.

In any community organized on a co-operative basis, the proper approach for extension in marketing is mostly through the local associations. In most Minnesota communities, the leaders and progressive farmers will be found connected with these associations. The large producers often stay out, but they are as a rule, in advance of the community in production and marketing. Also the very poor producers

often stay out; but they are not likely to be open-minded on the subject. The farmers who need extension most and who at the same time are open to it are generally found in the local associations. By locating the leaders within these as well as the paid employees, the specialists in marketing problems can readily enlist local aid in their work. These local men will spread the improved methods where they are most needed.

All three of the types of marketing extension—organization, business methods, and production—are likely fields for educational work. In the short space of this survey, one creamery was found that had been financed under such a scheme that no one could tell who owned it; several shipping associations were found which needed incorporation; and one which perhaps needed membership contracts; a local potato warehouse was found receiving a miscellaneous assortment of poorly sorted potatoes. Two other communities were paying for cream deliveries daily, an expensive and really useless practice. While Minnesota farmers have probably made as much progress in co-operation as those of any other state in the Union, there is still much room for improvement.

TECHNICAL BULLETIN 46 MARCH 1927

University of Minnesota
Agricultural Experiment Station

Inoculation of Alfalfa on Lime-Deficient Sandy Soils

Soil Transfer vs. Use of Cultures

By Frederick J. Alway and George H. Nesom
Division of Soils

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Summary	4
Introduction	5
Character of soils under observation	7
Methods of seeding and inoculation	9
Observations and seedings of 1919 to 1924 at Coon Creek	10
Alfalfa and sweet clover seedings in 1919	11
Alfalfa seedings in 1921 following sweet clover	15
Evidence of lime deficiency on adjacent land	18
Seedings of 1922, 1923, and 1924 on South field	23
Adequacy of mineral nutrients	29
Experiments with inoculated soil in 1924	30
Seeding after plowing under alfalfa	30
Trial of heavy application of soil	31
Trial of inoculated soil in addition to limestone	33
Experiments with inoculated soil in 1925	34
Alfalfa at Park Rapids	34
Alfalfa at Backus	36
Alfalfa at Crow Wing	37
West field at Coon Creek	39
Inoculation experiments in 1926	41
Experiment at Bemidji	42
Experiment at Crow Wing	43
Use of soil on Erickson South field	44
Trial of heavy application of culture	48
Discussion	55
Disturbing effect of drouth upon interpretation of data	55
Value of nitrogen determinations	55
Distribution of nodule bacteria in manure	55
Relative effectiveness of different methods	56
Probable cause of superiority of soil	59
Literature cited	61

ILLUSTRATIONS

Figure		Page
1.	Distribution of Coon Creek experimental fields	10
2.	Portion of south field at Coon Creek, included in experiments reported	11
3.	Effect of liming on yields of alfalfa on 1919 seeding on series A at Coon Creek	13
4.	Effect of liming on yields of alfalfa sown in 1921 on plots on series A at Coon Creek that had been in sweet clover in 1919 and 1920	16
5.	Effect of liming on yields of alfalfa in two cuttings on series B at Coon Creek	19
6.	Effect of liming on yields of three cuttings of alfalfa on series D at Coon Creek	22
7.	Effect of liming on yields of alfalfa on 1922 seeding on series A at Coon Creek	24
8.	Effect of liming on yields of alfalfa on 1923 seeding on series A at Coon Creek	27
9.	Effect of liming on yields of alfalfa on two seedings in 1924 on series A at Coon Creek	29
10.	A representative block on Erickson South field	45

SUMMARY

Observations and experiments are reported on the growth of alfalfa on widely scattered sandy fields in Minnesota, all more or less lime deficient toward both alfalfa and sweet clover, and on which the hydrogen-ion concentration of the surface soils, expressed as pH, was between 5.0 and 6.0. On one of the fields the crop had been under observation for eight consecutive seasons and on the others for much shorter periods.

When the land had been limed well in advance of the seeding, the use of artificial cultures was as effective as a heavy application of soil from an established field of alfalfa or sweet clover; but when it had not been limed, the soil transfer method was far the more effective in the case of the first seeding. Increasing the amount of culture to many times the usual rate did not make it as effective as soil transfer. The difference between the two methods appears to increase with the lime deficiency of the land being seeded.

The growing of alfalfa or sweet clover on such unlimed soils, even where the stand was thin and only a few of the plants were vigorous, satisfactorily inoculated a following seeding of alfalfa.

On these soils, when inoculation has been effected by soil transfer or by the previous growth of alfalfa or sweet clover, remunerative crops of alfalfa may be grown without lime. On all except the least lime-deficient fields, however, liming increases the yields more or less, even where satisfactorily inoculated by one of the above methods, but the increase actually due to liming, independent of its influence on inoculation, may be too small to be profitable, and during a drouth the beneficial effect may be entirely masked.

Liming experiments in which the current pure culture methods of inoculation are relied upon, are likely to lead to very erroneous conclusions as to the economy of liming such soils for alfalfa.

INOCULATION OF ALFALFA ON LIME-DEFICIENT SANDY SOILS

SOIL TRANSFER VS. USE OF CULTURES

By

FREDERICK J. ALWAY AND GEORGE H. NESOM

INTRODUCTION

The relative efficiency of the pure-culture method of inoculating legumes as compared with the soil-transfer methods, has been much discussed in this country during the last thirty years. Many soil bacteriologists are of the opinion that the pure cultures of *Bacillus radicicola* now obtainable from agricultural experiment stations and commercial firms are fully as efficient as soil from old, well established fields, but many American agronomists still consider soil transfer the more reliable method for alfalfa.

Löhnis and Fred, in their Textbook of Agricultural Bacteriology (1922), dealing with the inoculation of legumes, state:

"Before pure cultures became available for this purpose, soil was frequently taken as inoculum from fields where a good crop of the special kind of legume had been grown. The practice is still to be recommended when no reliable pure culture can be secured, provided the soil does not contain too many weeds and plant diseases. As a rule, however, efficient pure cultures for legume inoculation can easily be secured at present from Agricultural Experiment Stations, Agricultural Departments, and from many commercial firms" (13, pp. 271-272).

The only objection at present to the use of artificial cultures, according to a recent New Jersey experiment station extension bulletin (5, p. 3), is the expense involved, from 50 cents to $1.00 per acre. Farmers are assured that they may place a high degree of confidence in the product of the two firms which supply almost all the soil inoculants offered for sale in that state, whether they buy directly from these firms or through a retail dealer.

Stewart (17, pp. 138-139), in his recent book, "Alfalfa Growing in the United States and Canada," states that, according to American opinion, "soil inoculation is better than seed treatment with artificial cultures," and Oakley (1922) considers "the surest way (to inoculate alfalfa) is by scattering soil from a successful alfalfa field or from the roots of sweet clover or bur clover plants," mentioning the use of 250 to 500 pounds per acre, or the mixing of equal amounts of soil and seed (14, p. 14). In reply to an inquiry as to the basis of his

statement, Stewart writes that he secured the opinion, in writing or orally, of 37 Americans, most of them agronomists. The others were men who had had experience with alfalfa and who were in a position to have an opinion in this matter. Twenty-six stated definitely that soil inoculation was superior, seven that there was no difference, as far as they could see; and the remaining four that, under their conditions, they considered the use of a culture the better method.

General interest in the United States in the possibility of the use of pure cultures of *Bacillus radicicola* began with the work of J. F. Duggar in Alabama in 1897 (6). For most of the legumes with which he worked, he used Nitragin imported from Germany, comparing the relative advantages and disadvantages of the pure culture and soil transfer methods (6, pp. 480-482). Several common practices in inoculation, frequently described in later years, seem to have been first recommended in their present form by him in 1897, viz: the spreading broadcast of a ton or two per acre of soil from an old field of the leguminous crop in question, the starting of a small plot of the desired legume in order to provide inoculating soil for later years, and the mixing of the seed with inoculated soil where the latter was scarce.

Four years later the Bureau of Plant Industry of the United States Department of Agriculture inaugurated an investigation of the possibility of the use of pure cultures, and in 1905 this was placed in charge of Kellerman, who, six years later, in a careful review of the situation (9), while admitting that the claim of enthusiasts on the subject of pure culture inoculation to the effect that with proper precautions it was at least as certain as the use of soil from fields where similar leguminous crops have been grown for extended periods, "might be valid where the soil is well adapted to a leguminous crop," stated that "in soils not well adapted to a leguminous crop, however, there seems to be no doubt that soil from old fields gives much better promise of successful inoculation." In his publications between 1905 and 1913, Kellerman repeatedly emphasized that in order to obtain success with pure cultures the soil must be adapted to the growth of the leguminous crop in question, and in the case of alfalfa the soil must in many cases be brought into proper condition by more or less heavy liming (10, p. 7). He strongly opposed accepting as conclusive the results obtained on a single type of soil as to the relative efficiency of the pure culture method, compared with that of soil transfer (11, p. 73; 12). He alone, among the investigators, appears to have suspected that the relative efficiency of the two methods in any particular case might depend upon the character of the soil upon which they were being compared.

The most interesting recent contributions on the subject are probably those of the investigators at Rothamsted, where Russell (15, p. 5) considers that Thornton, by the addition of a very small amount of acid calcium phosphate to a suspension of the bacteria in skimmilk (18, pp. 7-8), has now devised a method for alfalfa that overcomes the previous trouble in ensuring inoculation by the use of pure culture.

CHARACTER OF SOILS UNDER OBSERVATION

The University of Minnesota has six widely distributed groups of experimental fields with sandy soil, viz: at Coon Creek, Becker, Crow Wing, Backus, Park Rapids, and Bemidji, all lying north and slightly northwest of St. Paul, at distances, respectively, of 18, 33, 110, 142, 160, and 190 miles. They are being devoted chiefly to a study of their deficiencies in lime and mineral nutrients, with alfalfa and the clovers as the main trial crops. Experiments with these legumes were started at Coon Creek in 1919; at Crow Wing, Backus, and Bemidji in 1922; and at Becker and Park Rapids in 1924. The texture and the hydrogen-ion concentration values of the soil and subsoil of these fields are illustrated in Tables I and II. The moisture equivalents from typical plots on the experimental farm at St. Paul and on two experimental fields with silt loam soils—Marshall silt loam at Kenyon and Tama silt loam at Caledonia—are given for comparison in order to bring out the coarseness of texture on the sand fields. The fractional values of the moisture equivalents are omitted, they having little significance in such a comparison.

TABLE I

MOISTURE EQUIVALENTS OF MINNESOTA SAND EXPERIMENTAL FIELDS IN COMPARISON WITH THOSE OF THE UNIVERSITY FARM AT ST. PAUL AND TWO EXPERIMENTAL FIELDS WITH SILT LOAM SOIL

	Coon Creek										
Depth ft.	South field	North field	Anderson field	Becker	Crow Wing	Backus	Park Rapids	Bemidj	Univ. Farm	Caledonia	Kenyon
1	5	4	4	10	6	8	13	6	24	27	26
2	4	3	3	6	5	6	4	4	24	27	26
3	3	3	2	4	3	4	2	3	23	28	24
4	2	2	2	2	3	4	1	3	16	28	23
5	2	2	1	2	3	4	1	3	2	27	22
6	2	2	1	2	3	4	1	3	1	26	20

During the last eight years determinations have been made of the moisture equivalents of many sets of soil samples from the Coon Creek South and North fields, taken to a depth of 6 feet or more, and of many samples from the surface of these fields. These have shown a general homogeneity of the soil.

TABLE II

HYDROGEN-ION CONCENTRATION OF REPRESENTATIVE PROFILES OF THE MINNESOTA SAND EXPERIMENTAL FIELDS

Depth	Coon Creek							
	North field	South field	Anderson field	Becker	Crow Wing	Backus	Park Rapids	Bemidji
ft.	pH	pH	pH	pH	pH	pH	pH	pH
1*	5.3	5.2	5.5	5.4	5.4	5.6	5.0	5.7
1†	5.7	5.2	5.7	5.5	5.8	5.3	5.1	6.6
2	6.1	5.9	5.9	5.6	5.8	5.3	6.2	6.5
3	6.2	6.1	5.9	5.5	5.9	5.5	6.4	6.3
4	6.4	6.4	..	..	5.9	6.1	8.4	6.3
5	6.4	6.4	..	..	5.7	5.9	8.4	7.0
6	6.4	6.5	..	..	5.6	..	8.4	7.3

* Upper half.
† Lower half.

In the early part of November, 1926, in order to learn the present condition of the unlimed plots, composite samples to a depth of 6 inches were collected from many of the control plots dealt with in this paper (Table III) and the hydrogen-ion concentration was determined. In all cases the gas chain electrometric method was employed, using a bubbling hydrogen electrode vessel and constant mechanical shaking.

TABLE III

HYDROGEN-ION CONCENTRATION, EXPRESSED AS pH, OF SURFACE 6 INCHES OF SOIL FROM UNLIMED, UNFERTILIZED PLOTS ON MINNESOTA SAND EXPERIMENTAL FIELDS

Coon Creek Fields					
South field, Series A 1921 seeding		South field, Series B Unlimed quarter		South field, Series D Unlimed quarter	
Plot	pH	Plot	pH	Plot	pH
1	5.3	1	5.4	1	5.3
6	5.1	2	5.2	2	5.2
11	5.2	6	5.2	6	5.3
15	5.2	12	5.2	12	5.2
20	5.3	13	5.2	13	5.2
25	5.3	17	5.3	17	5.2
West field		Anderson field		Erickson West field	
G- 1 to 20	5.0	A-12	5.5	B- 3	5.4
G-21 to 40	5.1	B- 9	5.6	B-10	5.5
L- 1 to 20	5.1	B-11	5.3	C-15	5.4
L-21 to 40	5.2	B-13	5.4	D- 7	5.7
South field, Series A 1919 and 1924 seeding		Swanson field		Erickson South field	
15	5.3	A- 4	5.5	IV-b-3	5.2
20	5.2	B- 2	5.4	IV-a-3	5.4
25	5.4	B- 7	5.3		
Northern Fields					
Crow Wing, 1925 seeding		Crow Wing, 1926 seeding		Becker, 1924 seeding	
A-3	5.8	B- 1	5.8	1-C	5.4
A-5	5.8	B- 5	5.5	1-F	5.4
B-3	5.6	B-10	5.7	7-C	5.3
B-5	5.7	B-15	5.7	7-F	5.4
Park Rapids 1924 seeding		Backus, 1925 seeding		Bemidji	
F-10	5.8	B- 1	6.0	1-8 in S-1	5.6
F-12	5.5	B- 8	5.6	1-8 in S-4	5.6
F-14	5.6	B-15	5.8	1-8 in S-7	5.9

The data in Tables II and III show that the surface soils on all these sand experimental fields are acid, but not necessarily that they are lime deficient. The lime deficiency of the fields referred to as distinctly lime deficient has been established by alfalfa liming experiments. The Bemidji fields are very slightly, if at all, lime deficient, altho the hydrogen-ion concentration of the surface, as pH, was between 5.6 and 5.8. Soil acidity and lime deficiency, while more or less related, are not synonymous terms (3, p. 5). Where applications of calcium carbonate do not increase the yields of the common clovers, but increase those of more sensitive crops such as alfalfa and sweet clover, the soil is to be regarded as lime deficient toward only the latter.

METHODS OF SEEDING AND INOCULATION

The seed was usually sown with a press drill, but was sometimes broadcast with a wheelbarrow seeder or, more rarely, by hand. A cultipacker was used in preparing the seedbed, the aim being to have the seedbed very firm, as free of weeds as feasible, and as moist as obtainable. In later years most of the seedings were made as soon as possible after a good rain.

Only the Grimm variety of alfalfa was used, except a one-rod strip on the 1919 seeding on Series A at Coon Creek, where seed bought as "common" was sown. This has suffered more winter injury than the Grimm which was sown parallel with it on the same day, and none of the date from it are used in this bulletin.

The liming materials employed include ground limestone, hydrated lime, and marl, the last both dry and wet. In any particular field, plot, or seeding, the choice was determined by the purpose of the experiment or by the convenience of supply.

Before the experiments were started, neither alfalfa nor sweet clover had ever been sown on any of the fields, nor had volunteer plants of either been seen on them.

The method of inoculation used in each seeding is indicated below. Unless it is clearly stated to the contrary, the seed was, in every case, inoculated with artificial cultures secured from two commercial sources, one being referred to as Q and the other as X. The amount used has always been somewhat in excess of that advised in the directions accompanying the package, which will be referred to in this paper as the usual rate. Usually the seed has been sown within a few hours of the treatment, and seldom has more than a day elapsed between the mixing of the culture with the seed and the completion of the seeding. In all seedings from 1919 to 1924, culture Q was used, and during 1925 and 1926 culture X was used exclusively. In a few cases in the earlier years, as a precautionary measure, soil from a well established alfalfa

or sweet clover field was mixed with the seed before sowing, or scattered over the plots and harrowed, in addition to the use of culture on the seed. In some of the experiments in the last three seasons, heavy applications of inoculating soil, 1 to 4 tons per acre, have been worked into the soil at the time of seeding the alfalfa.

OBSERVATIONS ON SEEDINGS OF 1919 TO 1924 AT COON CREEK

The fields of the Coon Creek group (Fig. 1), about eighteen miles northwest of the experiment station, are located on two soil types—Merrimac loamy sand and Hinckley fine sand. The South, North, West, and two Erickson fields are on the former, which occurs on a level outwash plain of the glacial Mississippi River; while the Anderson and Swanson fields are on the other type, which is found on rounded knolls and hills, the material consisting of wind-blown sand from the adjacent outwash plain. Both were originally covered by oaks and both drift severely when bare. The former type is the less drouthy because of its somewhat finer subsoil.

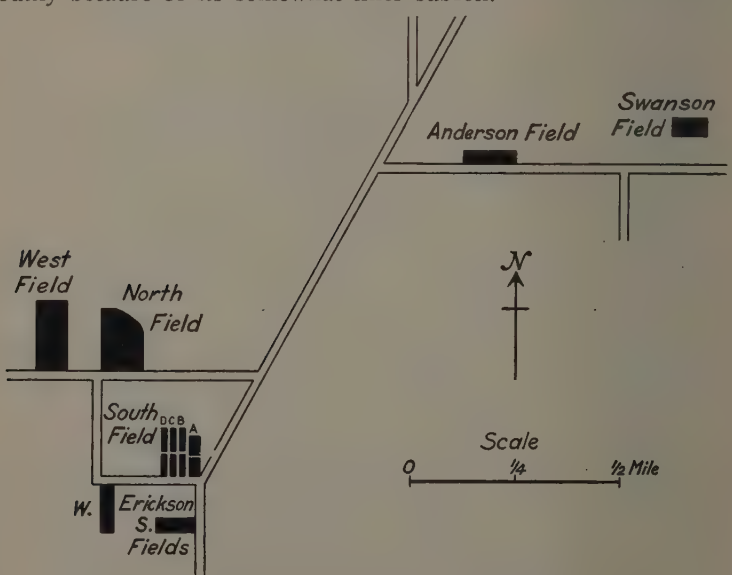


Fig. 1. Distribution of Coon Creek Experimental Fields

The portion of the South field involved in the experiments had been under cultivation about thirty years before the University obtained the lease of it, being cropped to winter rye, corn, and oats. Red clover had often been seeded with the small grains, but seldom, if more than once, had a stand been secured. At the time it was leased it carried a rather thin stand of medium red clover. Very little manure had been applied to this part of the field.

Alfalfa and Sweet Clover Seedings in 1919[1]

As soon as possession had been secured, in April, 1919, four series, A, B, C, and D, were laid out, each in two blocks separated by a roadway one rod wide, the north block to be a duplicate, so far as treatment of the soil is concerned, of the south (Fig. 2). During the second week of May, Series A was plowed and staked out into 28 twentieth-acre plots, separated by 2-foot paths.

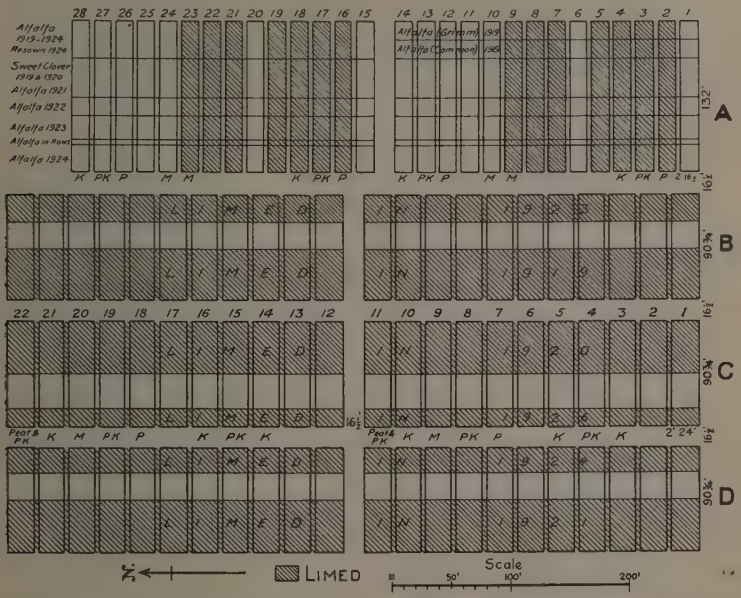


Fig. 2. Portion of South Field at Coon Creek, Included in Experiments Reported

In 1919 the crops seeded on Series A were: from east to west, Grimm alfalfa, 1 rod; common alfalfa, 1 rod; white sweet clover, 1 rod; yellow sweet clover, 1 rod; alsike clover, 1 rod; medium red clover, 1 rod; mammoth clover, 1 rod; white clover, 7½ feet; and soybeans, 9 feet.

Six of the plots were left as controls while the others were given various applications of very finely ground limestone, commercial fertilizer, and stable manure, as indicated in Table IV. Each plot, as soon as the applications to it had been completed, was disked and harrowed, driving the team in the direction of its longer axis in order to minimize the dragging of the applied materials from plot to plot. Control plots were given the same kind and amount of cultivation as the others. During the first week of June the whole series was seeded to nine legume crops, each crossing all 28 plots (Fig. 2). Alfalfa and

[1] James E. Chapman, since 1922 a member of the staff of the North Dakota Agricultural Experiment Station, was in charge of the work at Coon Creek during the seasons of 1919, 1920, and part of 1921.

sweet clover, which were sown with a wheelbarrow seeder, were inoculated with the artificial culture Q, and as a further precaution 400 pounds per acre of soil from an established field of alfalfa on University Farm was at once scattered over this portion of the series and harrowed in with the seed. As a result of very poor stands of alfalfa and the clovers and a dense growth of weeds, all the legumes, except the soybeans, were disked up on July 7. The land was well disked and harrowed from east to west, and a week later, following a rain of 0.9 inch, was reseeded according to the original plan, the same culture being again used on the alfalfa and sweet clover. On all the plots full, uniform stands of alfalfa were obtained and uniform but thin stands of the sweet and common clovers. Few weeds appeared and for the rest of the growing season the weather was very favorable.

TABLE IV
APPLICATIONS OF GROUND LIMESTONE AND FERTILIZERS ON PLOTS OF SERIES A

Plots	Applications and rates per acre
1, 15	None
2, 16	Limestone, 4 tons in 1919; phosphoric acid 88 lbs. in '19, 32 lbs. in '20, 88 lbs. in '24, 88 lbs. in '25, 88 lbs. in '26
3, 17	Limestone, 4 tons in 1919; phosphoric acid 88 lbs. in '19, 32 lbs. in '20, 88 lbs. in '24, 88 lbs. in '25, 88 lbs. in '26; potash 120 lbs. in '19, 112 lbs. in '20, 120 lbs. in '24, 100 lbs. in '25, 100 lbs. in '26
4, 18	Limestone, 4 tons in 1919; potash 120 lbs. in '19, 112 lbs. in '20, 120 lbs. in '24, 100 lbs. in '25, 100 lbs. in '26
5, 19	Limestone, 4 tons in 1919
6, 20	None
7, 21	Limestone, 2 tons in 1919
8, 22	Limestone, 8 tons in 1919
9, 23	Limestone, 4 tons in 1919; manure 10 tons in '19, 10 tons in '24 10 tons in '25, 10 tons in '26
10, 24	Manure 10 tons in 1919, 10 tons in '24, 10 tons in '25, 10 tons in '26
11, 25	None
12, 26	Phosphoric acid 88 lbs. in 1919, 32 lbs. in '20, 88 lbs. in '24, 88 lbs. in '25, 88 lbs. in '26
13, 27	Phosphoric acid 88 lbs. in 1919, 32 lbs. in '20, 88 lbs. in '24, 88 lbs. in '25, 88 lbs. in '26; potash, 120 lbs. in '19, 112 lbs. in '20, 120 lbs. in '24, 100 lbs. in '25, 100 lbs. in '26
14, 28	Potash 120 lbs. in 1919, 112 lbs. in '20, 120 lbs. in '24, 100 lbs. in '25, 100 lbs. in '26

The alfalfa and sweet clover on all plots came through the winter of 1919-20 with apparently uninjured stands, but all four common clovers were so largely killed that the plots were plowed up and reseeded about the middle of May.

Alfalfa of the 1919 seeding.—In the first crop season (1920) the alfalfa, which was mowed twice, showed a striking effect of the lime (Table V and Fig. 3), the average yield on the 6 limed plots being 2.11 tons and that on the 6 unlimed plots only 0.31 ton, an increase of 580 per cent. On all the limed plots the plants were tall

and dark green while on the unlimed plots nearly all were short and yellow. A few scattered green plants were observed in May and the number increased as the season advanced.

During the following winter most of the alfalfa on the unlimed plots died, apparently leaving only the scattered plants which had become green before the close of the growing season. The alfalfa on the limed plots suffered little or no winter injury. In 1921 the three cuttings showed increases from liming of 254, 271, and 383 per cent, respectively (Table V).

In 1922 the beneficial effect of the liming was almost as great. On the north block, Plots 15 to 28, the alfalfa was cut for hay only once, the second growth being left for seed. In 1923 the first growth on these 14 plots was left for seed, no hay being cut from them that season. In the spring of 1924 all the 1919 seeding of alfalfa on the 14 plots, both common and Grimm, was plowed under and the well prepared soil was resown to alfalfa, an experiment dealt with later in this paper.

The yields from 1923 to 1926 have not greatly altered the indication of lime deficiency, altho the difference between the averages for the limed and the unlimed has fallen to only about 100 per cent of the latter (Fig. 3).

On all 7 of the limed plots of the south block a good stand still remains from the original seeding, but on the unlimed plots the stands are thin and irregular.

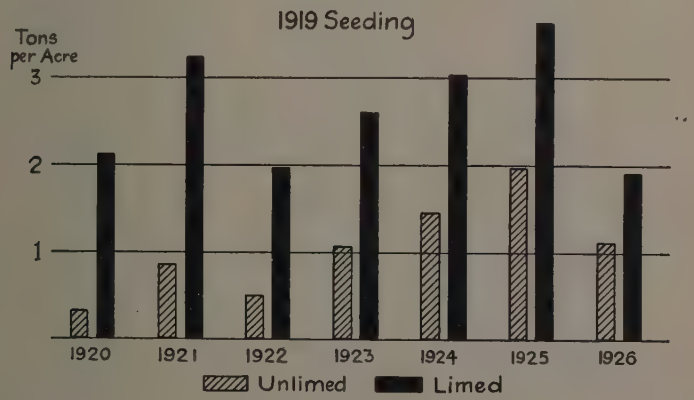


Fig. 3. Effect of Liming on Yields of Alfalfa on 1919 Seeding on Series A at Coon Creek

Sweet clover in 1920.—The effect of the lime was relatively even more marked on the sweet clover, which was cut only once, on June 18, the second growth being very light. The increase averaged 600 per cent with the white and 550 per cent with the yellow variety (Table VI).

TABLE V

EFFECT OF LIMING ON YIELDS OF ALFALFA ON 1919 SEEDING ON SERIES A AT COON CREEK

Plot No.	Application and rate per acre	1920		1921			1922		1823		1924		1925		1926		Total for 7 seasons
		First cutting	Second cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	
	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
1	None	0.16	0.08	0.34	0.17	0.08	0.12	0.05	0.20	0.11	0.25	0.14	0.25	0.17	0.26	0.17	2.13
6	do	.20	.16	.54	.36	.14	.40	.20	.77	.56	1.45	.58	1.81	1.07	1.31	.45	7.12
11	do	.20	.18	.97	.60	.25	.49	.27	.99	.59	1.58	.40	1.53	1.13	0.60	.47	7.59
15	do	.18	.08	.23	.14	.05	.28	*	*	*	†	...				...	
20	do	.20	.08	.40	.23	.12	.54	*	*	*	†	...				...	
25	do	.22	.16	.28	.16	.08	.13	*	*	*	†	...				...	
	Average	0.19	0.12	0.46	0.28	0.12	0.33	0.17	0.65	0.42	1.09	0.37	1.20	0.79	0.72	0.36	5.61
4	Limestone 4	0.88	1.20	1.69	0.97	0.48	1.15	0.73	1.57	0.92	2.17	0.66	2.26	1.78	1.29	1.02	19.13
7	do 2	0.96	1.28	1.94	1.21	.54	1.30	.85	1.87	.97	2.47	.93	2.22	1.61	1.16	0.84	20.51
8	do 8	1.12	1.28	1.57	1.09	.36	1.18	.66	1.63	.85	2.30	.57	1.86	1.14	0.77	0.67	17.47
19	do 4	0.76	1.04	1.45	0.97	.65	1.21	*	*	*	†	...				...	
21	do 2	0.84	1.12	1.33	0.73	.65	1.08	*	*	*	†	...				...	
22	do 8	0.94	1.20	1.81	1.21	.78	1.27	*	*	*	†	...				...	
	Average	0.92	1.19	1.63	1.03	0.58	1.20	0.75	1.69	0.91	2.31	0.72	2.11	1.51	1.07	0.84	19.04
Increase from liming, per cent.....		384	892	254	271	383	264	341	160	117	112	95	76	91	49	133	239

* Yields of hay not determined, being left for seed.

† Plowed up and reseeded.

TABLE VI

EFFECT OF LIMING ON YIELD OF SWEET CLOVER IN 1920 ON SERIES A AT COON CREEK
In 1921 the plots were plowed and seeded to alfalfa with no additional application

Plot No.	Application and rate per acre	White variety	Yellow variety
	tons	tons	tons
1	None	0.04	0.05
6	do	.03	.04
11	do	.02	.02
15	do	.07	.03
20	do	.03	.02
25	do	.10	.09
	Average	0.05	0.04
5	Limestone 4	0.37	0.37
7	do 2	.23	.20
8	do 8	.52	.52
19	do 4	.33	.15
21	do 2	.11	.11
22	do 8	.57	.23
	Average	0.35	0.26
	Increase from liming, per cent	600	550

Alfalfa Seeding in 1921 Following Sweet Clover

The portion of Series A (Fig. 2) that had been in sweet clover in 1919 and 1920 was plowed at the end of April, 1921, and seeded to alfalfa on May 14, no culture or soil for inoculation being used. At the end of June the resulting stand was so uneven and weeds were so abundant that the land was disked and kept clean until July 14, when it was reseeded to alfalfa without inoculation. On all the plots an excellent stand was obtained, but on the unlimed ones the plants were yellow and smaller than on the limed. Early in September this seeding provided a very striking demonstration of the benefits of liming. In October the plants on the unlimed plots were much improved in color. During the first week in November, from 60 to 200 plants were collected from each of Plots 1, 5, 6, 8, and 11 and examined for nodules, which were found on the roots of almost all, those from the unlimed as well as those from the limed plots.

All the evidence of the first three seasons, up to the winter of 1921-22, indicated a marked initial lime deficiency on this 33-foot strip on the 28 plots, but in 1922 the results were very different and quite unexpected.

During May and early June, 1922, the plants on all the unlimed portions of this seeding improved rapidly, and after the first cutting showed no very striking difference from those on the adjacent limed plots. Evidently the plants were fully inoculated, had found in the subsoil a supply of lime that was at least almost adequate, and did not suffer seriously from the acidity of the surface soil. With the

first cutting, the average increase from liming (Table VII) was only 64 per cent and with the second only 47 per cent. In the same season, in the 1919 seeding on the adjacent portion of the same plots, the increases were 264 and 341 per cent, respectively, and in the first crop season (1920) they had been 384 and 892 per cent. The differences in yield between the limed and the unlimed plots of the 1921 seeding in the following four seasons became smaller and smaller, falling to 28 per cent in 1923, to 11 per cent in 1924, and to 6 per cent in 1925, until in 1926, a very dry season, it has disappeared (Fig. 4).

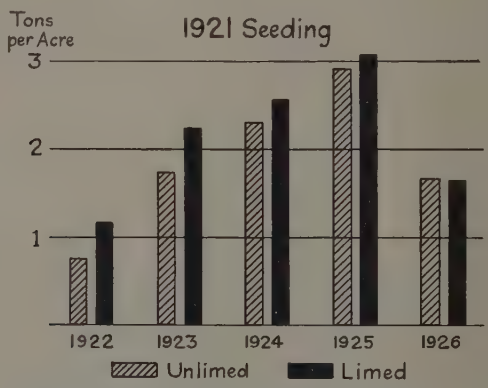


Fig. 4. Effect of Liming on Yields of Alfalfa Sown in 1921 on Plots on Series A at Coon Creek, That Had Been in Sweet Clover During 1919 and 1920

A comparison of Figures 3 and 4 brings out the great difference in behavior between the two seedings. The total yield per acre from the 10 cuttings in the five crop seasons averaged 9.40 tons on the 6 unlimed plots and only 1.36 tons, or 14 per cent, more on the 6 limed plots.

The question of lime deficiency.—At the end of the season of 1926 samples of the surface 6 inches of soil were collected from the portions of the 6 control plots that had been seeded to sweet clover in 1919 and also from the portions of the north 3 control plots seeded to alfalfa at the same time and the hydrogen-ion concentration of each was determined (Table III). The concentration, expressed as pH, varied only between 5.1 and 5.4.

If the only evidence of lime deficiency of the east 66 feet of Series A were the yields of the 1919 seedings of alfalfa and sweet clover (Tables V and VI and Fig. 3) and the present soil reaction, it would certainly be concluded that the soil was initially very lime deficient, and that liming is indispensable for the successful production of alfalfa.

TABLE VII

EFFECT OF LIMING ON YIELD OF ALFALFA ON 1921 SEEDING ON SERIES A AT COON CREEK

All the plots had been in sweet clover in 1919 and 1920

Plot	Application and rate per acre	1922		1923		1924		1925		1926		Total for 5 seasons
		First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	
	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
1	None	0.54	0.42	1.45	0.85	1.90	0.46	1.87	1.48	0.80	0.75	10.52
6	do	.48	.30	0.91	.56	1.69	.48	1.80	1.28	0.92	.85	9.27
11	do	.36	.30	0.91	.52	1.37	.55	1.42	0.98	0.82	.74	7.97
15	do	.42	.30	1.21	.93	1.98	.88	1.54	1.34	1.16	.93	10.69
20	do	.42	.27	1.03	.57	1.65	.66	1.60	1.36	0.85	.78	9.19
25	do	.48	.21	0.97	.56	1.77	.48	1.84	1.01	0.74	.69	8.75
	Average	0.45	0.30	1.08	0.67	1.73	0.58	1.68	1.24	0.88	0.79	9.40
5	Limestone 4	0.73	0.42	1.51	0.81	2.06	0.79	1.96	1.48	1.01	0.93	11.70
7	do 2	.79	.45	1.45	.69	1.86	.40	1.66	1.35	0.98	.81	10.44
8	do 8	.79	.48	1.63	.93	2.06	.56	1.81	1.21	0.87	.73	11.07
19	do 4	.66	.42	1.33	.77	1.45	.75	1.55	1.36	0.95	.77	10.11
21	do 2	.79	.45	1.45	.89	2.06	.62	1.82	1.52	0.66	.81	11.07
22	do 8	.66	.42	1.33	.69	2.14	.71	1.74	1.04	0.74	.72	10.19
	Average	0.74	0.44	1.45	0.80	1.94	0.64	1.76	1.33	0.87	0.79	10.76
	Increase from liming, per cent	64	47	34	19	12	10	5	7	−1	0	14

On the other hand, if the only evidence on the matter were the yields of alfalfa from the 1921 seeding, it would be concluded that the lime deficiency is slight, the application of lime not necessary and of doubtful economic advantage.

During the following three seasons, 1922 to 1924, the west half of A was gradually seeded to alfalfa, but before considering these seedings, it seems desirable to consider the evidence as to initial lime deficiency furnished by the three series to the west—B, C, and D.

Evidence of Lime Deficiency on Adjacent Land

The 66 plots of Series B, C, and D were devoted for five years to an experiment planned to determine the effect of commercial fertilizers, with and without lime, on the crops in a three-year rotation. The treatments are indicated in Figure 2. Ground limestone, at the rate of 4 tons per acre, was applied to the west half of B in May, 1919, to the east half of C in September, 1920, and to the west half of D in the summer of 1921. The crop history of these series previous to 1919 had been the same as that of A. Since that time it has been as shown in Table VIII.

TABLE VIII

CROPS ON SERIES B, C, AND D AT COON CREEK, 1919 TO 1926

Crop season	Series B	Series C	Series D
1919	Medium red clover	Winter rye	Winter rye
1920	Winter rye	Potatoes	Corn
1921	Medium red clover	Winter rye	Corn and potatoes
1922	Potatoes	Hubam clover	Winter rye
1923	Winter rye	Potatoes	Medium red and alsike clover and sweet clover
1924	Alfalfa and volunteer rye	Winter rye	Corn and potatoes
1925	Alfalfa	Medium red clover, sweet clover and alfalfa	Winter rye and alfalfa
1926	Alfalfa	Alfalfa and sweet clover seeded at different dates	Alfalfa

Series B.—On Series B medium red clover was seeded to winter rye in the spring of 1920. A fair stand was secured but most of the plants died during the following winter. In 1921 there was only one cutting, on June 22. The yield for the 22 plots averaged 0.44 ton per acre on the unlimed half and 0.41 ton on the limed.

The series was planted to potatoes in 1922 and after their removal was seeded to winter rye. Medium red clover sown in this in the spring of 1923 failed to make a stand. After harvesting the rye the stubble was plowed shallow, and on August 11 ground limestone, at the rate of 4 tons per acre, was spread on the east quarter. The object of this was to determine whether the earliness of an application influenced its effectiveness, this quarter being compared with the west

half, which had been limed four years before. The whole series was then disked, harrowed, cultipacked, and two days later seeded to alfalfa, using culture Q at the usual rate. Very few weeds, but much volunteer rye, appeared. At first there was a good stand of alfalfa on all three parts of every plot, but almost from the beginning there were marked differences between the three parts. On the west half, limed in 1919, all the plants were dark green and vigorous, while on the unlimed quarter nearly all were yellow and small, the line of demarcation being sharp on each of the 22 plots. On the east quarter, limed just before seeding, while most of the plants were small and yellow, there were many scattered individuals and groups resembling those on the west half, and the number of these increased as the season advanced.

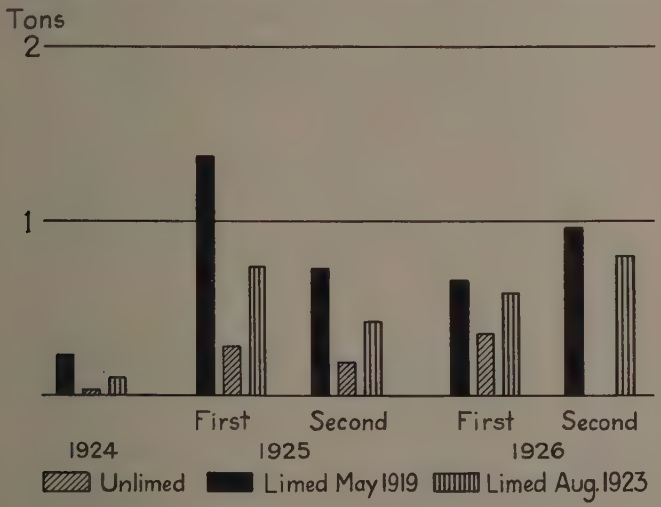


Fig. 5. Effect of Liming on Yields of Alfalfa in Two Cuttings on Series B at Coon Creek

Winter killing was severe on the late-limed quarter and much more so on the unlimed quarter, but was not observed on the early-limed half. The following May most of the remaining plants on the unlimed portion were still yellow; during the next two months part of these died and the rest became dark green. Evidently about all the dark green plants of the first fall survived and these were rather uniformly distributed. Throughout the early part of the season of 1924 the late-limed quarter showed a mottled appearance, with the proportion of green steadily increasing. The volunteer rye, which was uniform in stand on the different plots, was harvested and the growth of alfalfa that followed was mowed on October 25. The yields were light, even on the best plots, but on the late-limed quarter they were three times as heavy, and on the early-limed half seven times as heavy, as on the unlimed portion (Table IX and Fig. 5). The two cuttings in 1925

showed similar altho less marked differences. With the first cutting in 1926 the unlimed portion gave much the lowest yields. On account of drouth, the thinner stand on the late-limed portion yielded about the same as the thick stand on the early limed. As the unlimed quarter was plowed after the first cutting in 1926, there are no yields on this from a second cutting.

TABLE IX

EFFECT OF LIMING ON YIELD OF ALFALFA ON SERIES B AT COON CREEK SEEDED IN AUGUST, 1923, ON RYE STUBBLE

The series had never been in alfalfa or sweet clover

Plot	West side Limed in 1919	Center Never limed	East side Limed just before seeding
	1924 Only one cutting		
	tons	tons	tons
1	0.23	0.03	0.14
2	.26	.02	.09
6	.22	.04	.09
12	.23	.04	.09
13	.24	.03	.07
17	.20	.04	.12
Average	0.23	0.03	0.10
	1925 First cutting		
1	1.53	0.21	1.11
2	1.15	.21	1.11
6	1.27	.25	0.69
12	1.37	.39	0.87
13	1.42	.31	0.31
17	1.45	.33	0.31
Average	1.36	0.28	0.73
	1925 Second cutting		
1	0.69	0.27	0.48
2	.75	.15	.50
6	.88	.15	.59
12	.71	.24	.46
13	.71	.13	.27
17	.61	.21	.22
Average	0.72	0.19	0.42
	1926 First cutting		
1	0.65	0.31	0.59
2	.68	.29	.66
6	.66	.17	.73
12	.72	.27	.65
13	.62	.35	.44
17	.64	...	.44
Average	0.66	0.28	0.58
	Total in four cuttings		
1	3.10	0.82	2.32
2	2.84	.67	2.36
6	3.03	.61	2.10
12	3.03	.94	2.07
13	2.99	.82	1.09
17	2.90	...	1.09
Average	2.98	0.77	1.84

Series C.—The east half of Series C was limed in September, 1920, and sown to winter rye. The following spring medium red clover was seeded in the rye, but the stand died out before harvest. In May, 1922, the series was plowed and sown to Hubam clover inoculated with culture Q. A fair stand resulted but the growth was very light on all plots, especially on the unlimed half, on which the plants were very small and yellow. On the limed half the yield was more than four times as heavy as on the unlimed (Table X).

TABLE X

EFFECT OF LIMING ON YIELDS OF HUBAM CLOVER IN 1921 AND OF MEDIUM RED CLOVER IN 1925 ON SERIES C AT COON CREEK

Plot	Hubam clover in 1921		Medium red clover in 1925					
			First cutting, June 22		Second cutting, August 4		Two cuttings	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
	tons	tons	tons	tons	tons	tons	tons	tons
1	0.05	0.36	0.48	0.75	0.22	0.44	0.70	1.19
2	.09	.36	.38	1.29	.13	.78	.51	2.07
6	.05	.30	.11	0.72	.06	.58	.17	1.30
12	.09	.18	.53	1.29	.08	.61	.61	1.90
13	.05	.24	.04	0.90	.00	.40	.04	1.30
17	.05	.24	.30	1.20	.01	.59	.31	1.79
Average	0.06	0.28	0.31	1.02	0.08	0.57	0.39	1.59

In the fall of 1923, following a crop of potatoes, the whole series was sown to rye, and in the spring of 1924 medium red clover was seeded on the west 60 feet, occupying all the unlimed portion of every plot and a third of the limed. Alfalfa and sweet clover were sown on the rest of the limed half. Good stands of all three legumes were at first obtained. On the limed half these remained at the time the rye was harvested and, except red clover on some of the plots, also through the following winter. On the unlimed half, as the rye approached maturity a great many of the red clover plants died and the killing during the following winter was much more severe. In 1925 the rainfall was very favorable until the time of the first cutting, which was followed by an exceptionally severe drouth. The yields (Table X) averaged four times as heavy on the limed as on the unlimed portion—evidence of lime deficiency toward even red clover. There is nothing to indicate any less deficiency of lime on C than on B and the east part of A.

Series D.—The west half of Series D was limed in the summer of 1921 and the whole sown to winter rye. At the end of the next April sweet clover was seeded on the west 15 feet of the limed half and a mixture of medium red and alsike clover on the remainder. Only

thin stands of red clover were obtained and the yields in 1923 were very light, the single cutting averaging only 0.14 ton on the limed portion and 0.09 ton on the unlimed.

In 1924 an experiment somewhat similar to that reported for Series B was started on this series, the east quarter being limed during the first ten days of September, just after a crop of potatoes had been removed. The series was well cultivated and seeded to winter rye. Alfalfa, inoculated with culture Q, was at once sown on Plots 1 to 11 but no legume on Plots 12 to 22. A fair stand appeared but the plants were very small when winter came and practically all died before spring. On April 21, 1925, alfalfa was seeded in the rye with a press drill on all 22 plots, culture X being used. A good stand appeared on all portions of the plots but on the unlimed part most of the plants remained small and yellow, and most of these died before the rye was ready to be harvested. On the early-limed half there was a full stand of dark green plants and these persist to the present time (November, 1926). On the late-limed quarter the alfalfa did better than on the corresponding part of Series B, but many of the plants were yellow and many died before the rye was harvested in July. During the winter of 1925-26 most of the remaining yellow plants died, thus leaving on each of the 22 plots a very thin stand on the center, unlimed portion, and a rather thin but uniform stand on the late-limed portion. In the three cuttings of 1926, the yields on the early-limed portion averaged over 30 times as much as on the unlimed (Table XI and Fig. 6).

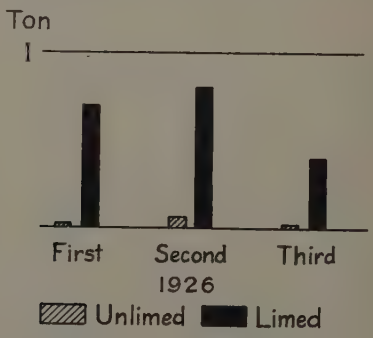


Fig. 6. Effect of Liming on Yields of Three Cuttings of Alfalfa on Series D at Coon Creek

The crops have given evidence of as great an initial lime deficiency on Series B, C, and D as on the east half of Series A. The samples of surface soil from the 12 control plots on B and D, taken at the same time as those from A, show a similar hydrogen-ion concentration, as pH, of 5.2 to 5.4 (Table III).

TABLE XI

EFFECT OF LIMING ON YIELD, IN 1926, OF ALFALFA SEEDED IN RYE IN 1925 ON SERIES D AT COON CREEK

Plot	West side Limed in 1921	Center Never limed	East side Limed Sept. 1924
	First cutting		
	tons	tons	tons
1	0.72	0.01	0.48
2	.79	.01	.43
6	.58	.02	.45
12	.58	.01	.44
13	.76	.03	.51
17	.78	.01	.62
Average	0.70	0.01	0.49
	Second cutting		
1	0.86	0.02	0.91
2	.85	.01	.78
6	.74	.01	.85
12	.70	.03	.62
13	.84	.07	.72
17	.84	.04	.73
Average	0.80	0 03	0.77
	Third cutting		
1	0.36	0.01	0.50
2	.41	.01	.54
6	.43	.01	.42
12	.41	.02	.33
13	.38	.03	.42
17	.43	.01	.33
Average	0.40	0.01	0.42
Total of 3 cuttings	1.90	0.05	1.68

Seedings of 1922, 1923, and 1924 on South Field

During 1922, 1923, and 1924 the remainder of Series A was seeded to alfalfa (Fig. 2). The differences in growth and yield between limed and unlimed plots, with these three seedings, were by no means so striking as with the 1919 seeding nor so slight in the first crop year as was the 1921 seeding, which followed sweet clover.

As stated previously, the four common clovers sown just west of the sweet clover in 1919 killed out during the following winter. In May, 1920, the land was plowed and resown to the same legumes, good stands of all being obtained. There was insufficient growth for a cutting in that season. All came through the winter without serious injury, and by the middle of May the effect of the liming was evident on all four clovers. On the unlimed plots the stand was thin, tho fairly uniform; on all the limed plots the plants were both much more numerous and much larger. Alsike showed less benefit than medium red and mammoth clovers. White clover showed much the same response as alsike but by mistake it was disked up at the end of May. During the growing season the rainfall was so unfavorable for the common

clovers that the yields were light, even on the limed plots. The average yields of cured hay for the same 12 plots dealt with in Table V were:

			Tons per acre		Tons per acre
Medium red,	two cuttings,	unlimed	0.29	limed	—0.45
Mammoth,	do	do	.56	do	.68
Alsike,	one cutting,	do	0.47	do	0.47

1922 Seeding.—On April 29, 1922, alfalfa was seeded on the east 15-foot strip of the above mentioned land and also in three rows, 16 inches apart, 20 feet farther to the west (Fig. 2). The seed was treated with culture Q. On the intervening 20 feet, Hubam clover was sown, inoculated as was the alfalfa. The west 4 feet of Hubam was in rows 16 inches apart and kept free of weeds, like the adjacent rows of alfalfa.

A good stand was secured on all the limed plots and a thinner, but comparatively uniform, stand on the unlimed. The growth of Hubam on the broadcast portion, even on the limed plots, was so poor that the yields were not considered worth determining, and on the unlimed plots it was much poorer still. In the rows there was much less difference, only 42 per cent increase from liming (Table XII).

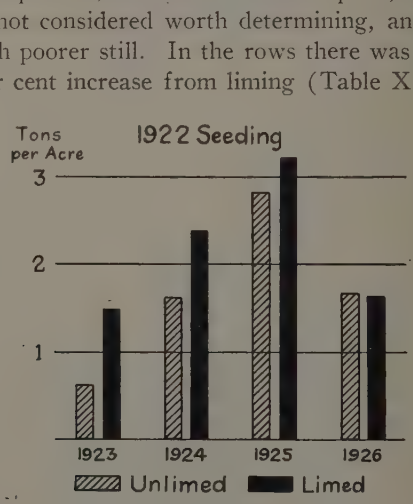


Fig. 7. Effect of Liming on Yields of Alfalfa on 1922 Seeding on Series A at Coon Creek

Throughout that season and the next the difference in appearance and yields of the broadcast alfalfa, in favor of liming, was so pronounced (Table XIII and Fig. 7) that the success of the alfalfa on the unlimed plots of the 1921 seeding, which by that time had become very evident, was still considered exceptional, and was attributed to unusually favorable weather which had allowed the plants to live until their roots reached the calcareous subsoil (3, p. 26).

TABLE XII

EFFECT OF LIMING ON YIELDS OF HUBAM CLOVER AND ALFALFA SEEDED IN ROWS ON SERIES A AT COON CREEK IN 1922

Plot No.	Application and rate per acre	Hubam clover 1922	Alfalfa									
			1923		1924		1925			1926		Total for 4 seasons
			First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	Third cutting	First cutting	Second cutting	
	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
1	None	0.36	0.73	0.73	1.38	0.58	1.46	0.89	0.45	0.43	0.49	7.14
6	do	.46	0.66	.53	1.31	0.52	1.44	0.97	0.46	0.40	.38	6.67
11	do	.49	0.66	.63	1.60	1.09	1.91	2.03	0.76	0.69	.65	10.02
15	do	.45	0.82	.82	2.33	1.29	1.04	1.52	0.86	0.83	.65	10.16
20	do	.52	1.25	.99	2.65	2.00	1.82	1.79	0.95	0.62	.58	12.65
25	do	.52	0.92	.89	3.11	1.76	2.06	1.74	1.03	1.22	.91	13.64
	Average	0.48	0.84	0.76	2.06	1.21	1.62	1.49	0.75	0.70	0.61	10.04
5	Limestone 4	0.82	1.15	1.02	2.21	0.89	1.88	1.37	0.79	0.54	0.47	10.32
7	do 2	.59	0.92	0.73	1.77	0.87	1.39	1.35	0.62	0.36	.39	8.40
8	do 8	.69	1.19	0.99	2.47	1.11	1.87	1.60	0.66	0.45	.43	10.77
19	do 4	.72	1.72	1.52	3.78	1.98	1.95	1.73	1.01	1.15	.71	15.55
21	do 2	.57	1.52	1.45	3.25	2.05	1.88	1.77	1.05	0.66	.74	14.37
22	do 8	.69	1.52	1.32	2.91	1.72	1.92	1.92	1.17	0.97	.78	14.23
	Average	0.68	1.34	1.17	2.73	1.44	1.81	1.62	0.88	0.69	0.59	12.27
Increase from liming, per cent.....		42	59	54	32	19	12	9	17	—1	—3	22

TABLE XIII

EFFECT OF LIMING ON YIELD OF ALFALFA ON 1922 SEEDING ON SERIES A AT COON CREEK

Plot No.	Application and rate per acre	1923		1924		1925		1926		Total for 4 seasons
		First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	First cutting	Second cutting	
	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
1	None	0.54	0.21	0.90	0.18	1.41	1.06	0.70	0.62	5.62
6	do	.54	.12	1.21	.38	1.95	1.21	1.08	.86	7.35
11	do	.18	.12	.72	.40	1.27	.60	.97	.75	5.01
15	do	.42	.24	1.33	.57	1.98	1.20	.92	.69	7.35
20	do	.54	.30	1.51	.53	1.87	1.29	.97	.80	7.81
25	do	.52	.18	1.51	.45	1.86	1.21	.91	.78	7.42
	Average	0.46	0.19	1.20	0.42	1.72	1.09	0.92	0.75	6.76
5	Limestone 4	1.09	0.42	1.57	0.27	2.02	1.25	0.91	0.75	8.25
7	do 2	0.85	.30	1.51	.40	1.90	1.24	0.81	.73	7.74
8	do 8	1.09	.60	1.87	.28	1.59	1.42	0.80	.67	8.32
19	do 4	1.03	.42	1.81	.73	1.94	1.42	1.19	.70	9.24
21	do 2	0.97	.60	2.05	.61	1.99	1.39	0.80	.69	9.10
22	do 8	1.21	.36	2.47	.80	1.92	1.23	0.93	.78	9.70
	Average	1.04	0.45	1.88	0.51	1.89	1.32	0.91	0.72	8.72
Increase from liming, per cent		126	137	57	21	10	21	—1	—4	29

In the rows of alfalfa which were kept free of weeds, the proportion of surviving plants was much higher and the marked differences between limed and unlimed plots disappeared sooner (Table XIII).

In 1925 the benefit of liming was not marked on the 1922 seeding, and in 1926, so far as the yields indicate, it disappeared, but there is still a better stand on the limed plots.

1923 Seeding.—On June 22, 1923, the 20-foot strip that had been in Hubam in 1922 was seeded to alfalfa, with no inoculation. The differences between limed and unlimed plots in this seeding have been much like those of the 1922 seedings, becoming less each year (Table XIV and Fig. 8).

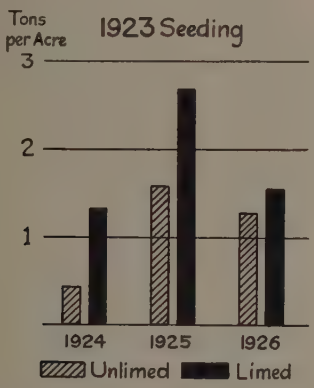


Fig. 8. Effect of Liming on Yields of Alfalfa on 1923 Seeding on Series A at Coon Creek

TABLE XIV

EFFECT OF LIMING ON YIELD OF ALFALFA ON 1923 SEEDING ON SERIES A AT COON CREEK
Hubam clover occupied the plots in 1922

Plot No.	Application and rate per acre	1924 First cutting	1924 Second cutting	1925 First cutting	1925 Second cutting	1926 First cutting	1926 Second cutting	Total 1924-26
	tons	tons	tons	tons	tons	tons	tons	tons
1	None	0.42	0.18	1.15	0.80	0.48	0.57	3.60
6	do	.42	.14	0.99	.82	.60	.66	3.66
11	do	.12	.07	0.36	.12	.30	.30	1.27
15	do	.24	.12	0.89	.57	.84	.61	3.27
20	do	.30	.16	0.80	.94	.94	.56	3.70
25	do	.30	.17	1.35	.83	.93	.94	4.52
	Average	0.30	0.14	0.92	0.68	0.68	0.61	3.34
5	Limestone 4	1.09	0.27	1.56	1.21	0.75	0.73	5.61
7	do 2	1.02	.18	1.54	1.14	0.77	.75	5.40
8	do 8	1.21	.27	1.60	0.97	0.73	.69	5.47
19	do 4	0.98	.23	1.60	1.37	1.29	.69	6.16
21	do 2	1.21	.25	1.68	1.25	0.92	.65	5.96
22	do 8	1.09	.18	1.39	0.93	0.83	.65	5.07
	Average	1.10	0.23	1.56	1.14	0.88	0.69	5.60
Increase from liming, per cent		267	64	70	68	29	13	68

TABLE XV

EFFECT OF LIMING ON YIELDS OF ALFALFA ON TWO 1924 SEEDINGS ON SERIES A AT COON CREEK

Both groups of plots were seeded on the same day. Those on the east had been in alfalfa for the preceding five years, while those on the west had never been in alfalfa or sweet clover.

Plot No.	Application and rate per acre	West group					East group				
		1925		1926			1925		1926		
		First cutting	Second cutting	First cutting	Second cutting	Two seasons	First cutting	Second cutting	First cutting	Second cutting	Two seasons
	Tons	tons	tons	tons	tons	tons	tons	tons	tons	tons	tons
1	None	1.27	0.97	0.57	0.66	3.47	...	...	...	...	...
6	do	0.94	.68	.37	.57	2.56	...	...	...	...	...
11	do	0.36	.42	.40	.53	1.71	...	...	...	...	...
15	do	0.97	.71	.60	.69	2.97	0.83	0.72	0.40	0.52	2.47
20	do	0.75	.66	.63	.63	2.67	0.93	.78	.57	.63	2.91
25	do	0.61	.28	.48	.53	1.90	1.00	.65	.58	.57	2.80
	Average	0.82	0.62	0.51	0.60	2.55	0.92	0.72	0.52	0.57	2.73
5	Limestone 4	1.60	1.07	0.51	0.68	3.86	...	...	...	...	...
7	do 2	1.23	1.05	.45	.62	3.35	...	...	...	...	...
8	do 8	1.26	0.71	.44	.65	3.06	...	...	...	...	...
19	do 4	1.53	1.16	.76	.66	4.11	1.34	0.90	0.59	0.66	3.49
21	do 2	1.38	0.80	.69	.65	3.52	1.20	.78	.46	.64	3.08
22	do 8	1.53	0.78	.78	.75	3.84	1.28	.80	.46	.74	3.28
	Average	1.42	0.93	0.60	0.67	3.62	1.27	0.83	0.50	0.68	3.28
	Increase from liming, per cent	73	50	18	12	42	38	15	—4	19	20

1924 Seeding.—On June 16, 1924, the 27-foot strip remaining on the west side of the series, which had been in soybeans and the common clovers during the preceding five years, was seeded to alfalfa, treating the seed with culture Q. The relative yields (Table XV) in 1925 and 1926 have been much like those of the first two years of the 1922 seeding. This may be seen from a comparison of the left half of Figure 9 with Figure 7.

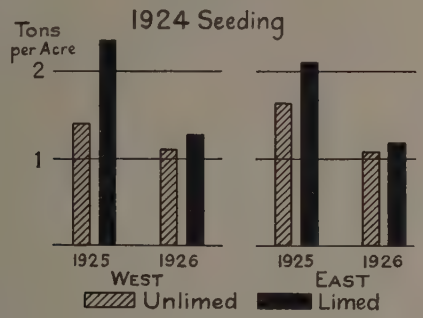


Fig. 9. Effect of Liming on Yields of Alfalfa on Two Seedings in 1924 on Series A at Coon Creek
The east plots had been in alfalfa from 1919 to 1924. while the west plots had not previously been in alfalfa or sweet clover

Adequacy of Mineral Nutrients

The soil of all these series is well supplied with potash, phosphate, and sulphur for alfalfa. Experiments with phosphate and potash alone and in combination, both with and without liming, apply to all seedings on Series A and to most of those on B, C, and D. The results with the first three seedings of alfalfa on A are reported in Table XVI, where the yields of the plots that received only 4 tons of ground limestone in 1919 are compared with those that received the same and in addition phosphate and potash at that time and in four later seasons (Table IV).

The most effect has been shown during the first two crop seasons and even then it was only slightly beneficial. For the seven crop seasons of the 1919 seeding there was no gain, —0.18 ton per acre; for the five crop seasons of the 1921 seeding, only 0.18 ton; and for the four of the third seeding, only 1.27 tons.

Sulphur is abundant in the soil. No sulphur fertilizer has been applied as such, but in 1919 the potash was applied in the form of sulphate of potash and half the phosphoric acid as ordinary acid phosphate. All the phosphate added in 1920 was in the form of acid phosphate and the potash fertilizer used was Nebraska potash salts, which carried a considerable proportion of sulphate.

TABLE XVI

EFFECT OF PHOSPHATE-POTASH APPLICATIONS ON YIELD OF ALFALFA ON LIMED PLOTS OF SERIES A AT COON CREEK

All received 4 tons per acre of limestone in May, 1919, and none afterwards. Phosphate and potash were applied in the spring of 1919, 1920, 1924, 1925, and 1926.

Plot	Fertilization	1920	1921	1922	1923	1924	1925	1926	Total
		Seeding of 1919							
		tons	tons	tons	tons	tons	tons	tons	tons
3	K+P*	2.18	3.02	1.85	2.43	2.95	3.44	2.22	18.09
17	do	2.34	3.51	...	...	...	...	...	...
	Average	2.26	3.26	1.85	2.43	2.95	3.44	2.22	18.41
5	None	2.08	3.14	1.88	2.49	2.83	4.04	2.31	18.77
19	do	1.80	3.07	...	...	...	...	...	...
	Average	1.94	3.10	1.88	2.49	2.83	4.04	2.31	18.59
	Increase with K+P*	0.32	0.16	—0.03	—0.06	0.12	—0.60	—0.09	—0.18
		Seeding of 1921							
3	K+P*	...	...	1.21	2.45	2.46	3.21	1.95	11.28
17	do	...	...	1.21	2.28	2.44	2.92	1.94	10.79
	Average	...	...	1.21	2.36	2.45	3.06	1.94	11.03
5	None	...	...	1.15	2.32	2.85	3.44	1.94	11.70
19	do	...	...	1.08	2.10	2.20	2.91	1.72	10.01
	Average	...	...	1.11	2.21	2.52	3.17	1.83	10.85
	Increase with K+P*	...	...	0.10	0.15	—0.07	—0.11	0.11	0.18
		Seeding of 1922							
3	K+P*	...	...	...	1.81	2.27	3.16	2.20	9.44
17	do	...	...	...	1.75	3.41	3.75	1.71	10.62
	Average	...	...	...	1.78	2.84	3.45	1.95	10.03
5	None	...	...	...	1.51	1.84	3.27	1.66	8.28
19	do	...	...	...	1.45	2.54	3.36	1.89	9.24
	Average	...	...	...	1.48	2.19	3.31	1.77	8.76
	Increase with K+P*	...	...	...	0.30	0.65	0.14	0.18	1.27

* K=potash; P=phosphate.

Experiments with Inoculated Soil in 1924

By the spring of 1924 the conclusion had been reached that the growing of even a very thin stand of alfalfa or sweet clover on these fields contributed something favorable to the growth of a new seeding of alfalfa that was not furnished by the commercial culture and that this was something else than merely a great number of bacteria. To test this, half of the land seeded to alfalfa on Series A in 1919 was plowed up and reseeded to alfalfa; also a heavy application of soil from one of these plowed plots was made to some unlimed plots on a near-by field which was being sown to alfalfa for the first time.

Seeding After Plowing Under Alfalfa

In May, 1924, all the alfalfa of the 1919 seeding, both common and Grimm, on Plots 15 to 28 of Series A was plowed under. Alfalfa seed, treated with culture Q at the usual rate, was sown on the same date (June 16) and in the same manner as on the west 27 feet of the same series.

On all the plots thick stands resulted and still persist. The yellow, stunted plants that had characterized the unlimed plots in previous seedings, at least for a time, were entirely absent. While all the plants on the unlimed plots were of uniformly good color, but somewhat lighter, the growth was somewhat less vigorous during 1924 and 1925 than on the limed plots. On the first cutting of the first crop year there was a difference in yield of only 38 per cent in favor of the limed plots and on the second cutting of only 15 per cent. In 1926 the difference was much less (Table XV and Fig. 9).

Trial of Heavy Application of Soil

The Anderson field, which is on Hinckley fine sand, located on a knoll about a mile from the South field (Fig. 1), had been farmed for many years but had finally become so unproductive that for several years it had been allowed to lie idle. It was rented by the University in 1924 in order to determine whether alfalfa, by means of liming, could be made a successful crop on soil so much inferior to that of the South field. The trial of the heavy application of soil from Series A was limited to three plots, the experiment with the soil being only incidental to the main experiment on this field.

The rather thin growth of weeds occupying the land was plowed under early in July, 1924; 25 plots were laid out, and the hydrogen-ion concentration of the surface 6 inches of soil on each was determined. This was found to be much alike on all. Four plots were left as controls while various applications were made to the others on July 25 to 28 (Table XVII). Ground limestone was used at rates of 2, 4, and 8 tons per acre; and marl, from an adjacent pit and carrying about 35 per cent of water, at 40 tons per acre. On three plots inoculating soil from Plot 22 on Series A in the South field was applied at the rate of 2 tons per acre. That plot in 1919 had been given 8 tons per acre of limestone and seeded to alfalfa, which earlier in 1924 had been plowed up and the plot reseeded. On July 30 all the plots were seeded to alfalfa inoculated with commercial culture Q.

TABLE XVII

EFFECT OF TREATMENTS ON YIELD OF ALFALFA ON ANDERSON FIELD AT COON CREEK
Seeded July 30, 1924. All seed treated with culture

Plot	Application and rate per acre	1925 First cutting	1925 Second cutting	1925 Two cuttings	1926 First cutting	1926 Second cutting	1926 Two cuttings	Total for two seasons
		tons	tons	tons	tons	tons	tons	tons
A-7	None	0.25	0.25	...	0.40	0.62		
A-12	do	.46	.20	...	.44	.76		
B-4	do	.83	.44	...	.44	.80		
B-9	do	.34	.38	...	.48	.60		
	Average	0.47	0.32	0.63	0.44	0.69	1.13	1.76
A-3	Limestone, 2 tons	1.02	0.58	...	0.68	0.73		
A-8	do	1.13	.59	...	.67	.92		
B-5	do	1.08	.60	...	.48	.79		
	Average	1.08	0.59	1.67	0.61	0.81	1.42	3.09
A-1	Limestone, 4 tons	1.28	0.60	...	0.63	0.69		
A-4	do	1.03	.45	...	.57	.72		
A-9	do	1.27	.48	...	.60	.69		
A-13	do	1.37	.43	...	.63	.82		
B-6	do	1.18	.62	...	.48	.81		
	Average	1.23	0.52	1.75	0.58	0.75	1.33	3.08
A-5	Limestone, 8 tons	1.09	0.50	...	0.50	0.75		
A-10	do	1.19	.52	...	.62	.74		
B-7	do	1.16	.70	...	.62	.80		
	Average	1.15	0.57	1.72	0.58	076	1.34	3.06
A-6	Marl, 40 tons	1.20	0.56	...	0.53	0.70		
A-11	do	1.25	.48	...	.53	.74		
B-8	do	1.11	.68	...	.56	.79		
	Average	1.19	0.57	1.76	0.54	0.74	1.28	3.04
A-2	Soil, 2 tons	0.94	0.46	...	0.52	0.66		
B-11	do	.93	.52	...	.59	.75		
B-13	do	.70	.44	...	.40	.56		
	Average	0.86	0.47	1.33	0.50	0.66	1.16	2.49
B-3	Limestone, 4 tons	1.46	0.64	...	0.42	0.77		
B-10	and manure, 10 tons	1.23	.79	...	.66	.82		
B-12	do	1.39	.70	...	.68	.76		
	Average	1.36	0.71	2.07	0.59	0.78	1.37	3.44

A thick stand of plants appeared on all the plots, and on all that had received limestone, marl, or inoculating soil the plants were dark green and vigorous. On the control plots most of them showed the usual characteristic stunted growth and yellow color, and during the following winter and summer most of those on three of these plots died, leaving a thin, rather uniform stand of green plants. On one control plot, B-4, there was a much better growth and fewer plants died. There was no appreciable winter injury on any of the plots treated with limestone, marl, or soil. In the fall of 1924, on the three plots to which soil was applied, the plants were not quite so large or

quite so dark green as those on the limed or marled plots, but they still were so thrifty in appearance that if there had been no adjacent limed plots for comparison their condition would have been considered entirely satisfactory. In 1925 the plants on these three plots appeared similar to those on the limed plots until in June, as they approached bloom, when they fell behind a little. On all the limed, marled, and soil-treated plots, during the last two dry seasons, the thick stands have been a disadvantage, causing injury from lack of moisture, and in every cutting most of the plants dried up without coming into bloom, while on the control plots the much smaller number of plants have kept green, grown much taller, and bloomed. On all the treated plots better yields would doubtless have been obtained if the stands had been much thinner. Wet weather followed the second cutting in 1926, made on July 31, and the resulting growth was far behind on all the treated plots than on the controls, being thicker but not taller. On the soil-treated plots this growth was similar to that on the limed and marled plots. On all it has been left for winter protection.

Trial of Inoculated Soil in Addition to Limestone

At Becker.—Alfalfa, treated with culture Q at the usual rate, was sown on a block of fortieth-acre plots on the Becker experimental field on June 18, 1924. These included four to which inoculating soil from Coon Creek had been applied the day before at the rate of 800 pounds per acre. These four, with many others, had received 3 tons per acre of ground limestone during the first week of the preceding November, while some had been left with no application. The reaction of the surface soil (Table III) on the Becker fields is very similar to that on the Coon Creek fields.

The addition of inoculating soil to the lime has been without effect upon either the appearance of the plants in their early stages of growth or the yields of hay (Table XVIII). In the first season the lime was distinctly beneficial, the control plots carrying a shorter and yellower growth and yielding less. During the winters of both 1924-25 and 1925-26 many plants on the unlimed plots died.

TABLE XVIII

EFFECT OF LIME AND INOCULATING SOIL ON YIELDS OF ALFALFA ON BECKER EXPERIMENTAL FIELD

Seed all treated with commercial culture and sown June 18, 1924

Plot	1925		1926		
	First cutting	Second cutting	First cutting	Second cutting	Total of 4 cuttings
	tons	tons	tons	tons	tons
A. No application of lime or inoculating soil					
A-7	0.63	0.57	0.44	0.45	2.09
C-7	.57	.51	.35	.39	1.82
F-7	.53	.47	.39	.39	1.78
H-7	.83	.79	.54	.58	2.74
Average	0.64	0.59	0.43	0.45	2.11
B. Application of ground limestone, 3 tons per acre in October, 1923					
A-2	0.72	0.65	0.37	0.51	2.25
A-4	.86	.71	.40	.51	2.48
D-2	.86	.68	.45	.57	2.56
D-4	.83	.61	.38	.44	2.26
Average	0.82	0.66	0.40	0.51	2.39
C. Application of ground limestone, 2 tons per acre in October, 1923, and 800 pounds per acre of inoculating soil on June 17, 1924					
A-3	0.81	0.65	0.36	0.44	2.26
A-5	.89	.96	.54	.63	3.02
D-3	.91	.62	.41	.42	2.36
D-5	.80	.48	.41	.45	2.14
Average	0.85	0.68	0.43	0.48	2.44

Experiments with Inoculated Soil in 1925

Following the encouraging results obtained on the Anderson field, experiments on the use of inoculating soil were started at Park Rapids, Backus, and Crow Wing, and a rather elaborate experiment was laid out at Coon Creek. The results from the first three support the conclusions of the earlier experiments at Coon Creek, while those from the last are not readily explainable.

Alfalfa at Park Rapids

The soil of the Park Rapids field is decidedly lime deficient toward alfalfa. The first season's seeding, 1924, using culture Q, included 24 plots of alfalfa with lime and the same number without. On all the unlimed plots in 1925 there was a large proportion of short yellow plants, while on all the others the plants were uniformly green. The relative yields in 1925 were as follows: controls, 100; with lime only, 180; with potash only, 170; with lime and potash, 300; with lime and phosphate, 170; with lime, phosphate, and potash, 300. In the winter of 1925-26 many plants died on the unlimed plots but few or none on the limed plots. The lime deficiency of the soil appeared to be established.

As the ground was freezing in November, 1924, wet, sticky marl, at a rate equivalent to about 2.5 tons of calcium carbonate per acre, was spread and disked in on the odd-numbered series from 19 to 26. On April 23, 1925, inoculating soil at the rate of 2 tons per acre was applied to all the most easterly (A) and the most westerly (H) plots on these 8 series. This soil was taken from a part of the field that had been marled in the fall of 1923 and sown to alfalfa the following May. The next day alfalfa was sown on A and B and sweet clover on H and D-E, culture X at the usual rate being used on both.

TABLE XIX

Effect of Inoculating Soil and Marl on Yields of Alfalfa and Sweet Clover on Park Rapids Experimental Field

Seed all treated with commercial culture and sown on April 24, 1925

Application and rate per acre	Alfalfa				Sweet clover			
	Plot	First cutting	Second cutting	Two cuttings	Plot	First cutting	Second cutting	Two cuttings
		tons	tons	tons		tons	tons	tons
No marl or soil	20-B	0.10	0.33	0.43	20-E	0.13	0.08	0.21
do	22-B	.08	.05	.13	22-E	.13	.05	.18
do	24-B	.04	.04	.08	24-E	.09	.05	.14
do	26-B	.08	.19	.27	26-E	.14	.16	.30
Average		0.07	0.15	0.22		0.12	0.08	0.20
Soil, 2 tons	20-A	0.41	0.40	0.81	20-H	0.40	0.22	0.62
do	22-A	.32	.42	.74	22-H	.50	.32	.82
do	24-A	.13	.27	.40	24-H	.53	.26	.79
do	26-A	.20	.31	.51	26-H	.40	.31	.71
Average		0.26	0.35	0.61		0.46	0.28	0.74
Marl, 3 tons in 1925	19-B	0.18	0.26	0.44	19-E	0.29	0.20	0.49
do	21-B	.22	.42	.64	21-E	.40	.31	.71
do	23-B	.16	.15	.31	23-E	.22	.18	.40
do	25-B	.13	.14	.27	25-E	.18	.24	.42
Average		0.17	0.24	0.41		0.27	0.23	0.50
Marl, 3 tons and soil, 2 tons	19-A	0.38	0.44	0.82	19-H	0.47	0.42	0.89
do	21-A	.44	.49	.93	21-H	.76	.51	1.27
do	23-A	.31	.46	.77	23-H	.53	.43	.96
do	25-A	.17	.30	.47	25-H	.44	.35	.79
Average		0.32	0.42	0.75		0.55	0.43	0.98
None Average of 4 plots		0.07	0.15	0.22		0.12	0.08	0.20
Marl do		.17	.24	.41		.27	.23	.50
Soil do		.26	.35	.61		.46	.28	.74
Marl and soil do		.032	0.42	0.75		0.55	0.43	0.98

In 1926 the effect of both lime and soil was very evident on both legumes. The stand of alfalfa was good on every marled plot and almost as good on the unmarled plots that had been given soil, while on all plots that had received neither marl nor soil it was very thin. Owing to a prolonged drouth the yields were light, even on the best plots, but with each cutting they were heaviest on the plots that received both soil and marl, next on those that received soil alone, and lightest

on the untreated plots (Table XIX). At the close of the season of 1926, on the plots which had received no marl but had been given an application of soil there was a satisfactory stand of plants and they were dark green. On the marled plots there was a still thicker stand, there being far more plants than needed to give maximum yields, while on the untreated plots the stand was far too thin to justify leaving.

On the plots of sweet clover, the stands were thinner but the response to the various treatments was similar.

The beneficial effect of the soil on the marled plots at Park Rapids differs from our observations on the other fields. This may be attributed to the incomplete mixing of the marl with the soil, owing to the wet and frozen condition of the former, and to there being so little opportunity for interaction of marl and soil between the time of application and the time of seeding.

Alfalfa at Backus

An elaborate experiment started in 1922 has shown the lime deficiency of the Backus fields toward alfalfa to be about as distinct as that at Park Rapids. In 1925, on a field immediately adjacent to this experiment and with similar soil, an experiment was started with inoculating soil. The land had been in corn in 1923 and 1924 and for both crops had been liberally manured—in the second year with part of the winter's accumulation at a barn where alfalfa hay had been fed regularly and liberally. Early in June, 3 tons per acre of dry marl was applied and disked in on the west 33 feet of the tract, which is 850 feet from north to south and 56 feet from east to west. On July 10 the field was staked out into 32 plots, half on the marled portion and half on the unmarled. On each half four plots were left as controls and the others were treated with soil from a near-by plot limed in 1921 and sown to alfalfa in 1922, four rates—¼ ton, ½ ton, 1 ton, and 2 tons per acre—being used on the duplicate plots.

The soil was at once disked in and five days later the field was sown with alfalfa treated with culture X at the usual rate. A good stand resulted on all plots. During the rest of that season no beneficial effect of the inoculating soil was observed on the marled plots but on the others it was distinct and varied with the rate.

In 1926 the plots were carefully inspected by one of the authors on four dates—May 6, June 12, July 5, and August 30. The hay was cut twice—on July 13 and August 31. At the time of the first inspection the alfalfa on all the marled plots gave no evidence of winter killing, was very vigorous with 3 or 4 inches of new growth, and showed no effect of the inoculating soil. On the unmarled plots marked differences were observable. On those that had received no soil there was almost no growth and many of the plants had winter killed. On

those given 2 tons per acre of soil they were doing almost as well as on the adjacent marled plots and there was no winter killing. On the unlimed half, the 1-ton plots were inferior to the 2-ton, and the ¼-ton plots were superior to the control plots, with the ½-ton plots intermediate. The most marked difference in the series—0-, ¼-, ½-, 1- and 2-ton plots—was between 0 and ¼ ton. There was no doubt at that time as to the benefit of the soil application on the unmarled land but there was no evidence of any benefit on the marled.

The season was exceptionally dry, with resulting low yields on the best plots. From January 1 to March 31 the precipitation amounted to 2.57 inches; from April 1 to June 16 to only 0.9; with 2.95 inches between the last date and July 10, and 3.44 inches between that and the date of the second cutting, August 31.

The influence of a gravelly subsoil, which is very irregularly distributed over the field, became evident by June 12, at which time on the marled half the alfalfa was found to be dry and brittle on many entire plots and on parts of other plots. A similar condition existed on parts of a few of the unmarled plots. The thick stands on the former were at a great disadvantage, as is usual on such soils in periods of drouth. As a result, even the averages of the yields fail to indicate the effectiveness of the applications. The total for the two cuttings averaged only 1.6 tons per acre of hay on the marled portion, both on the plots that had received no soil and on those that were given 2 tons per acre, 1.3 tons on the unmarled plots given 2 tons per acre of soil, and 0.7 ton on those given neither soil nor marl.

By the time of the second cutting all evidence of uninoculated plants had disappeared except on the four untreated plots. On the soil-treated but unlimed plots the thickness of stand varied in general with the rate of application.

From the four detailed inspections it was evident that the inoculating soil had no distinct effect on the marled plots but was beneficial on the unmarled land, this benefit increasing with the rate of application. Even with the heaviest application, however, the alfalfa did not do nearly as well on the unmarled portion as it did on the marled portion that had received no soil.

Alfalfa at Crow Wing

The experiment started at Crow Wing included only 10 plots, three of which were left as controls, three given 3 tons per acre of inoculating soil from a near-by plot that had been treated with 3 tons per acre of limestone in 1921 and seeded to alfalfa the next summer, two given 3 tons per acre of dry marl, and the remaining two given both marl and inoculating soil. The seed, inoculated with culture X, was sown

on June 13. On all the plots a thick stand resulted and on all except the controls there was a vigorous growth of dark green plants, the color and growth being as good on the plots receiving only soil as on those receiving marl. On August 15 and 27, when careful examinations were made of every plot, the controls stood out sharply, with their smaller yellow plants.

During the following winter little or no killing occurred except on the controls and even on these enough plants survived to make a satisfactory stand. On May 9, by which time growth was well started, the stand on the controls was thinner and the growth smaller than on the marled plots; on all given either soil alone, or soil and marl, the stand and growth were alike and better than on those given only marl. On June 12, after a month of very dry weather, while the color was alike on all the plots and the relative stands the same as a month before, the plants on the controls were taller and showed fewer drying leaves. From that time on no distinct superiority was observed on the treated plots.

The analysis of the first cutting, July 10, gave no indication of any lack of inoculation, the nitrogen content being as high on the controls as on the other plots (Table XX).

TABLE XX

EFFECT OF MARL AND INOCULATING SOIL ON YIELDS AND NITROGEN CONTENT OF 1925 SEEDING OF ALFALFA AT CROW WING

Plot	Application and rate per acre	Yields per acre			Nitrogen content of first cutting
		First cutting	Second cutting	Two cuttings	
		tons	tons	tons	per cent
B-1	None	0.22	0.67	0.89	2.90
B-3	do	.30	.76	1.06	2.12
B-5	do	.31	.64	.95	2.80
	Average	0.28	0.69	0.97	2.94
A-1	Soil, 3 tons	0.33	0.72	1.05	2.66
A-3	do	.31	.88	1.19	2.83
A-5	do	.30	.68	.98	2.81
	Average	0.31	0.76	1.07	2.77
B-2	Marl, 3 tons	0.28	0.76	1.04	3.16
B-4	do	.29	.74	1.03	2.88
	Average	0.28	0.75	1.03	3.02
A-2	Marl, 3 tons and soil, 3 tons	0.29	0.67	0.96	2.70
A-4	do	.32	.70	1.02	2.94
	Average	0.30	0.68	0.98	2.87

After the second cutting, samples of the surface 6 inches of soil were taken from two controls and two soil treated plots and all were much alike in hydrogen-ion concentration, as pH, 5.6 to 5.8 (Table III).

West Field at Coon Creek

The most elaborate experiment with inoculating soil is that laid out on the West field (Fig. 1) at Coon Creek in 1925. Two cuttings of hay were removed from the plots in 1926. The results seem entirely out of harmony with all our other experiments and observations, and for this reason the experiment is given a fuller description.

A rectangle 800×156 feet was subdivided into seven series, G to M, each 20 feet wide. Six-foot alleys were left between H and I, and also between J and K, in order to prevent the dragging of limestone from the plots on I and J, which were to be given both limestone and inoculating soil, to those on H and K, which were to be left unlimed. On May 22 ground limestone at the rate of 3 tons per acre was applied to the whole of Series I, J, and M. Seven days later Series H, I, J, and K were subdivided, each into 40 plots 20×20 feet, giving 160 plots on the four series. On the same four series 96 of the plots were treated with inoculating soil taken from eight different sources, each a well established field or plot of alfalfa or sweet clover at Coon Creek or University Farm. Two of these sources had not been limed. Each soil was used at three rates—sandy soil from Coon Creek at ½, 1, and 2 tons; and silt loam from University Farm, ¼, ½, and 1 ton. With each rate of each of these eight inoculants there were four plots, two treated with ground limestone at 3 tons per acre and two unlimed. At the same time there was given to 12 plots, 6 on the limed series (I and J), and 6 on the unlimed series (H and K) a very heavy application of culture X mixed with surface soil taken from an unlimed plot at Coon Creek, on which neither alfalfa nor sweet clover had grown. The contents of three bottles of the culture, each enough for a bushel of seed, were well mixed with 250 pounds of the soil and one twelfth of this was scattered over each plot and at once worked in. This was about 100 times as much culture as, at the usual rate, would be mixed with the seed for this area.

On June 2 occurred a thunderstorm of tornadic proportions, blocking roads with uprooted trees, and wrecking barns. The wind was accompanied by rain, 1.8 inches falling in less than half an hour. In the slight depressions on the field the water collected as ponds, overflowed from these and swept over many of the plots, thus transferring both soluble and insoluble material from one plot to another. This storm was followed by a week of high winds which caused much drifting of sand on the field, notwithstanding the frequent use of disk and cultipacker to check it. On June 11 the whole field was sown to alfalfa, all the seed except that on Series G being treated with culture X at the usual rate. That for G was treated with neither culture nor soil, but was not sterilized.

A good stand resulted on all parts of the field. During the second week of October, in order to permit a careful study of the relation of the condition of the plants to the soil applications, the plots were staked out and paths cut around each. There was much variation from plot to plot and from one part to another on the unlimed plots but these differences were not associated with differences in the applications of soil. The series were crossed, almost at right angles and at irregular intervals, by strips 6 to 12 feet wide, on which the alfalfa showed a better color and growth, suggesting that these were where manure had been applied with a spreader.

During the winter of 1925-26 there was little killing on any of the plots. A detailed examination was made at the end of June, 1926, just before cutting the first crop of hay. At that time the alfalfa on all the plots was suffering from drouth, and the thicker the stand the more it showed the lack of moisture. In general, the stand on the limed series was thicker and the growth more uniform, altho shorter, than on the others. Wherever lime had been applied the plants were dark green, while elsewhere part of them were yellow and the others were a lighter green than on the limed plots. The soil applications showed no effect upon stand or growth on either the limed or the unlimed plots.

For the purpose of determining yields, C, L, and M were subdivided into 120 plots of the same size as those on the other series and the yield was determined on each of the 280 plots for both cuttings—July 1 and September 20.

The summary (Table XXI) indicates that the lime was beneficial but the soil applications and the culture were without effect upon the yield. At the close of the season there was a satisfactory stand of inoculated plants on all except 16 of the 280 plots, and these 16 formed five scattered groups on the unlimed series G, H, and K. No explanation of the partial failure of the stand on these is suggested.

The anomalous behavior of this field, including the successful stand on the unlimed series treated with neither lime nor soil and sown with untreated seed, is not to be attributed to a lesser acidity of the surface soil. In four samples collected from the unlimed plots after the winter of 1926-27 had set in, the hydrogen-ion concentration, as pH, was found to be 5.0, 5.1, 5.1, and 5.2. A block parallel with this rectangle and lying only 100 feet east of it had been laid out in 120 fortieth-acre plots in the summer of 1924 and the hydrogen-ion concentration of the surface soil of every plot was determined. In nearly all cases the value, expressed as pH, fell between 4.8 and 5.0.

TABLE XXI

EFFECT OF LIME AND INOCULATING SOIL ON YIELDS OF ALFALFA ON WEST FIELD AT COON CREEK IN 1926

Treatment of seed	Treatment of plot and rate per acre		No. of plots	Yield per acre		
	Limestone	Soil		First cutting	Second cutting	Two cuttings
	tons	tons		tons	tons	tons
None	None	None	40	0.48	0.63	1.11
Culture, at usual rate	do	do	66	.47	.61	1.08
do	do	0.25	4	.32	.48	0.80
do	do	0.50	16	.49	.58	1.07
do	do	1.00	16	.47	.51	1.02
do	do	2.00	12	.51	.60	1.11
do	3	None	66	.60	.73	1.33
do	3	0.25	4	.60	.69	1.29
do	3	0.50	16	.68	.71	1.39
do	3	1.00	16	.67	.70	1.37
do	3	2.00	12	.70	.72	1.42
None	None	*	6	.34	.46	0.80
do	3	*	6	0.58	0.67	1.25

* Soil treated very heavily with culture was applied in advance of seeding.

The explanation may lie in the manuring the land had received in the four seasons preceding the leasing of it by the University in 1924. For five or six years, at least, it had been in cultivated crops. Each year, in preparation for these, manure had been applied rather heavily, and probably not at all uniformly. It is only about 200 yards from the cow stables where all the alfalfa hay that had been produced on the Coon Creek experimental fields had been fed, beginning with the fall of 1920. Definite information regarding the manuring is not obtainable, as the man who had farmed the land died before the anomalous behavior of the field became evident.

The previous manuring was recognized as an objection at the time the experiment was started, but the block in question was the only available land conveniently located with respect to the other experimental fields at Coon Creek.

Inoculation Experiments in 1926

By the close of 1925 there was much evidence that soil upon which alfalfa or sweet clover had grown carried something that exerted a beneficial effect upon new seedings of alfalfa on such unlimed soils as these. In 1925 five additional experiments on the use of inoculating soil were started, one at Bemidji, one at Crow Wing, and three at Coon Creek—Erickson South field, Erickson West field, and Swanson field.

In order to secure more information during the first season as to the effect of the different treatments, plants were dug up from representative areas on more than 80 of the plots at the approach of winter, the early advent of which prevented the completion of the work. On each of these plots all the alfalfa plants from four square feet were

removed and separated at once into two groups—inoculated (carrying one or more nodules) and uninoculated—then thoroly washed, counted, oven-dried, and those of each group were weighed without separating the tops from the roots. Nitrogen determinations were made on many of these samples. On every plot sampled, a square, 12×12 inches, was marked out along the diagonals, 2 yards from each of the four corners. The four square blocks of soil, taken to the depth of the spade, were removed, placed on a screen, and the plants carefully separated from the soil, an operation which was greatly facilitated by the coarseness of the soil, its very moist condition, and the general absence of weeds. In some cases, probably, nodules became detached from the roots of inoculated plants. On a considerable number of large green plants no nodules were found, but it was very frequently observed, as these exceptional plants were being examined for nodules, that their roots had grown into distinct lumps of organic residues, which might account for their vigorous appearance.

Experiment at Bemidji

The soil on the Bemidji experimental field is regarded at most as only *very slightly* lime deficient toward alfalfa. An elaborate experiment, under way since 1922, has revealed no beneficial effect of liming except in the first summer, during which the plants on the limed plots made a somewhat better growth. There has been no significant difference in yield between controls and marled plots.

In the spring of 1926, a field that had never been in alfalfa or sweet clover or received much manure, was plowed and kept fallow until August in order to rid it of quack grass, with which it was badly infested. During the last week in July it was subdivided into 90 fortieth-acre plots and various applications were made of inoculated soil, marl, stable manure, and green manures. Alfalfa seed, treated with culture X at the usual rate, was sown immediately after a rain on August 4. A good stand was obtained on all the plots but the growth and color appeared slightly inferior on the controls. The hydrogen-ion concentrations of the surface 6 inches of the control plots, as pH, were between 5.6 and 5.9. During the second week of October the plants from four square feet on each of 42 plots were removed and examined as described above.

On all the plots there was a thick stand and the number of plants (30 to 50 per square foot) showed no relation to the treatment, but the proportion of plants with nodules was distinctly lower on the controls than on the plots treated with inoculating soil, marl, or the combination of these. On 10 of the 11 controls examined the percentage varied from 37 to 63, with an average of 48, but on the eleventh it was 80; with 10 tons per acre of stable manure, the percentages were 65, 71, and 72.

Freshly cut alfalfa, at the rate of 10 tons per acre, was plowed under on three plots and equal amounts of freshly cut sweet clover and oats on two sets of triplicate plots. One plot of each was sampled. On the plot with alfalfa, 68 per cent of the plants had nodules; on the one with sweet clover 45 per cent; and on that with oats 65 per cent. With one ton of marl the percentages were 64, 72, and 76, with an average of 71; with 2 tons of marl 70, 73, and 73, with an average of 72. With inoculating soil it was as follows:

	½ ton soil, per cent	1 ton soil per cent	2 tons soil per cent	4 tons soil per cent
Soil from unlimed plot of sweet clover.....	76 83	73 80	70 70	88 92
Soil from limed plot of sweet clover.....	87 89	94 97	89 92	94 99

The proportion was high and much alike on all. At each rate it was higher with the soil from the limed plot. The use of marl in addition to inoculating soil from the limed plot gave 82 and 90 per cent, no more than the soil alone.

On 36 plots the inoculated plants averaged about half as heavy again as the uninoculated, while on the other six there was no distinct difference, the ratio for the 42 plots averaging 1.6. There was no distinct connection between the treatment of the plot and the average weight of either inoculated or uninoculated plants.

Nitrogen determinations were made of both inoculated and uninoculated plants from 19 of the plots. In one case there was practically no difference, but in all others the nitrogen in the inoculated was from 0.15 to 0.77 per cent the higher.

Experiment at Crow Wing

A field at Crow Wing which had been under cultivation about 40 years without manuring or the growing of any legume and had been seeded to rye in the fall of 1925, was plowed in June and the land kept fallow until laid out in 40 tenth-acre plots. At the end of the first week of August most of these were given inoculating soil at the rates of ½, 1, 2, or 4 tons per acre and at once sown to alfalfa treated with culture X. On 8 plots no inoculating soil was used. Four of the untreated plots were divided each into four squares and three of the squares on each were sown with seed treated with the usual amount of culture, while the fourth was sown with seed given culture at 30 times the usual rate.

An inspection on October 20 showed no distinct difference in the stand from plot to plot, but there was a better color and growth and a higher proportion of inoculated plants on the soil-treated plots. On the plots left without a soil application there was no marked difference in either appearance or nodulation of the plants, between the quarter that

was sown with very heavily treated seed and the remainder. The early arrival of winter prevented a detailed study like that made on the Bemidji field.

Use of Soil on Erickson South Field

The rectangular tract used for the experiment on the Erickson field, containing about two and a half acres, lies only 150 yards south of the South field (Fig. 1). It had been in corn in 1925, and is part of a well managed private farm, which had for some years received regular applications of stable manure. No alfalfa or sweet clover had ever been sown on the part used for the experiment nor had manure been applied to this after the feeding of alfalfa hay was begun.

The experiment was planned to furnish information along three lines: (1) the extent to which inoculating soil could take the place of limestone, (2) the advantage on limed land of using inoculating soil in addition to an artificial culture, (3) the effect on the alfalfa of delaying the application of marl or ground limestone until just before seeding.

The field was divided into six series, I to VI, running east and west. On April 30, 1926, ground limestone was spread on Series I at the rate of 2 tons per acre and on Series II at 1 ton. The whole tract was then thoroly cultivated and divided by north and south lines into five equal blocks, *a, b, c, d,* and *e,* which on successive dates, each following a rain, were to be subdivided, given certain applications, and seeded. On *a,* the block to be seeded first, applications of ground limestone and marl were made on May 3 to the portions on Series III, V, and VI. Then the block was further subdivided into four north and south rectangles (Nos. 1 to 4) and inoculating soil, ½ ton per acre, was applied to No. 1; 1 ton to No. 2, and 2 tons to No. 4, while none was applied to No. 3 (Fig. 10). The whole block was then thoroly cultivated and next day was sown to alfalfa inoculated with culture X.

The four later seedings—of June 12, July 12, 22, and 31—were carried out in the same way. In each case, after a rain had well moistened the soil, the applications of inoculating soil were made on Nos. 1, 2, and 4, and of ground limestone and marl on Series III, V, and VI. These were thoroly worked in and alfalfa inoculated with culture X was seeded at once. Good stands were secured in each of these seedings but that of June 12 suffered some injury from drouth. The hydrogen-ion concentrations on two control plots, as pH, were 5.2 and 5.4 (Table III).

About the middle of October the plots were carefully compared. In blocks *a, b,* and *c,* all plots on each that had received limestone or marl, appeared alike in stand, color, and growth. On *d* and *e,* seeded on July 22 and July 31, the plants on III-3, which was not limed until just before seeding, were yellower and less vigorous. On V-3, given

limestone at the same time but at twice the rate, the growth appeared as vigorous as on the plots limed in April.

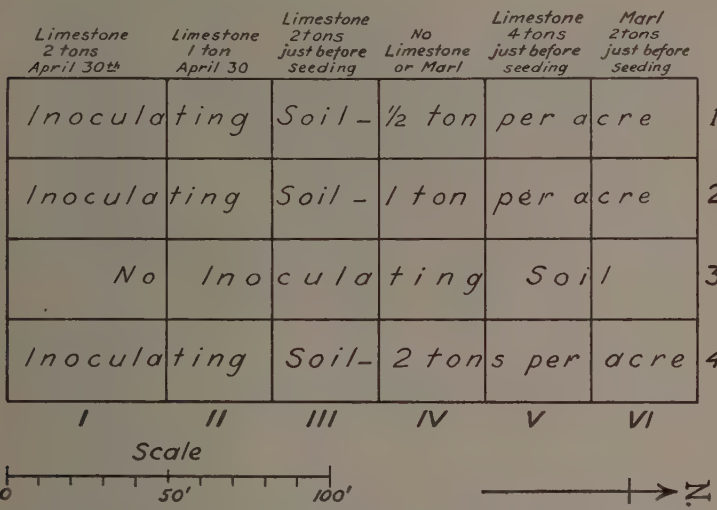


Fig. 10. A Representative Block on Erickson South Field
This shows time and rate of applications of limestone and marl and rate of application of inoculating soil, which was applied just before seeding.

Plants were gathered from the 16 plots of the last four seedings on the unlimed series, IV. On the part of the July 31 seeding that received no inoculating soil the five other plots were sampled. The number of plants on the unlimed plots (Table XXII) had not been increased by the application of soil, and on every plot, when winter set in, enough remained to constitute a full stand, provided they survive the winter and become inoculated early enough in 1927. The soil applications on every date greatly increased the proportion of plants with nodules, but the 2-ton application was not distinctly more effective than the ½-ton. On the untreated plots the percentage varied between 8 and 33, with an average of only 17; while on the soil-treated plots of corresponding dates it was in every case much higher, varying between 24 and 92 per cent, with an average for all of 56. On both untreated and treated plots the proportion was highest with the last seeding.

The average weight of the uninoculated plants, in each seeding, was much alike on all four plots. That of the inoculated plants was lowest on the untreated plot, and the later the seeding the more marked was the difference. This might be interpreted as indicating that most of the plants on the control plots on which nodules were found at the end of October, had not become inoculated as early as those on the treated plots. Increasing the rate of soil application did not increase the weight of either the inoculated or the uninoculated plants.

TABLE XXII

STAND, NODULATION, WEIGHT, AND NITROGEN CONTENT OF ALFALFA ON PLOTS OF THE UNLIMED SERIES, IV, ON THE ERICKSON SOUTH FIELD TO WHICH DIFFERENT AMOUNTS OF INOCULATING SOIL HAD BEEN APPLIED AT TIME OF SEEDING

Seed on all treated with culture at usual rate. All seedings in 1926. Plants collected during second half of October.

Plot	Rate of application per acre	June 12 seeding	July 12 seeding	July 22 seeding	July 31 seeding	Average
	tons					
		Number of plants from 4 square feet				
3	0.0	77	70	142	139	107
1	0.5	87	75	145	172	120
2	1.0	67	92	170	112	110
4	2.0	49	101	125	112	97
		Percentage of plants found inoculated				
3	0.0	8	14	12	33	17
1	0.5	51	27	62	77	54
2	1.0	44	24	59	92	55
4	2.0	53	35	76	73	59
		Average weight of inoculated plants, grams				
3	0.0	0.30	0.17	0.14	0.08	
1	0.5	.39	.49	.29	.22	
2	1.0	.43	.33	.22	.20	
4	2.0	0.40	0.30	0.22	0.19	
		Average weight of uninoculated plants, grams				
3	0.0	0.08	0.13	0.09	0.06	
1	0.5	.08	.20	.12	.07	
2	1.0	.12	.13	.08	.06	
4	2.0	0.08	0.09	0.07	0.09	
		Ratio of average weight of inoculated plants to that of uninoculated plants				
3	0.0	3.7	1.3	1.5	1.3	
1	0.5	4.9	2.4	2.4	3.1	
2	1.0	3.6	2.5	2.5	3.3	
4	2.0	2.7	3.3	3.1	2.1	
		Per cent nitrogen in inoculated plants				
3	0.0	3.58	2.59	2.75	3.05	
1	0.5	3.25	2.94	3.55	3.42	
2	1.0	3.41	2.95	2.98	3.69	
4	2.0	3.19	3.25	...	3.33	
		Per cent nitrogen in uninoculated plants				
3	0.0	2.20	2.45	2.23	2.42	
1	0.5	2.81	1.51	2.72	...	
2	1.0	2.64	1.83	2.47	2.35	
4	2.0	2.30	2.21	2.87	2.99	
		Excess of nitrogen in inoculated plants, per cent				
3	0.0	1.38	0.14	0.52	0.63	
1	0.5	0.44	1.43	.83	...	
2	1.0	0.77	1.12	0.51	1.34	
4	2.0	0.89	1.04	...	0.34	

The nitrogen content of the inoculated plants from each of the untreated plots was distinctly higher than that of the uninoculated plants from the same plot and not distinctly different from that of the inoculated plants from the soil-treated plots seeded on the same day.

TABLE XXIII

EFFECT ON ALFALFA OF TIME AND RATE OF LIMING AND OF RATE OF APPLICATION OF INOCULATING SOIL

Plots of July 31, 1926, seeding on Erickson South field. The seed had been treated with culture at the usual rate.

	No marl or limestone				No application of soil				
						Limestone			
	Soil 2 tons	Soil 1 ton	Soil 0.5 ton	No soil	Marl 2 tons July 30	2 tons July 30	4 tons July 30	1 ton April 30	2 tons April 30
Number of plants from 4 sq. ft.	112	112	172	139	118	107	117	131	115
Percentage of plants with nodules	73	92	77	33	95	78	77	70	94
Average weight of plants with nodules, grams	0.19	0.20	0.22	0.08	0.35	0.17	0.26	0.19	0.36
Average weight of plants without nodules, grams	0.09	0.06	0.07	0.06	0.13	0.12	0.09	0.10	0.10
Ratio of above average weights	2.10	3.30	3.10	1.30	2.70	1.40	2.90	1.90	3.60
Nitrogen in plants with nodules, per cent	3.33	3.69	3.42	3.05	3.33	3.63	3.72	3.84	3.60
Nitrogen in plants without nodules, per cent	2.99	2.35	...	2.42	2.79	2.99	2.82	3.41	2.62
Excess of nitrogen in plants with nodules, per cent	0.34	1.34	...	0.63	0.54	0.64	0.90	0.43	0.98

The data from the latest seeding (Table XXIII) indicate that the liming had not affected the thickness of stand but had more than doubled the proportion of inoculated plants and at least doubled the average weight of these. The increase in the average weight of the uninoculated plants may be due to the liming. In each plot the inoculated plants show a distinctly higher nitrogen content than the uninoculated. The soil, lime, and marl applications appear to have been about equally effective.

It seems safe to conclude that on this field the use of inoculating soil has greatly increased the proportion and growth of inoculated plants, has not affected the growth of the uninoculated, or the number of plants surviving at the end of the first season. Half a ton of soil per acre has been as effective as 2 tons and the effectiveness of this application has varied from seeding to seeding, altho all the soil was taken from the same plot of alfalfa.

Trial of Heavy Applications of Culture

Culture X, at 5, 10, and 30 times the usual rate, in comparison with the usual rate, was tried on unlimed plots on the West Erickson field and the Swanson field, both sown during the second week in August, 1926.

The West Erickson field is on the same farm as the South Erickson field and has a similar history, including the absence of alfalfa and sweet clover. It produced a crop of winter rye in 1926 and was plowed on August 10 and laid out in 60 plots, each 33×33 feet. Two days later marl was applied, at the rate of 3 tons per acre, to 14 plots; and inoculating soil, at 2 tons per acre, to 7 plots. The remaining 39 were given no inoculating soil or any form of lime. All were then well cultivated and the next day all were seeded to alfalfa as follows:

(1) 7 untreated plots with untreated but not sterilized seed.
(2) 7 " " " seed treated with culture at usual rate.
(3) 7 " " " " " " " " 5 times usual rate.
(4) 7 " " " " " " " " 10 " " "
(5) 7 " " " " " " " " 30 " " "
(6) 4 " " " " mixed with 4 times its weight of moist inoculating soil.
(7) 10 marled plots with seed treated with culture at usual rate.
(8) 4 " " " " mixed with 4 times its weight of moist inoculating soil.
(9) 7 plots, to which 3 tons per acre of inoculating soil had been applied, with untreated seed.

The Swanson field lies about half a mile east of the Anderson field (Fig. 1) and has a soil naturally similar. In 1926 it had been planted to corn, but on August 10, for the purpose of this experiment, the corn was pulled and removed from about an acre, the land was disked, and

24 plots, each 33×33 feet, were laid out. The next day marl was applied to 4 of these at the rate of 4 tons per acre, and inoculating soil to 3 at 2 tons per acre and to one at 4 tons per acre. The applications were at once well worked in and the following day all the plots were seeded to alfalfa as follows:

(1) 4 untreated plots with untreated but not sterilized seed.
(2) 3 " " " seed treated with culture at usual rate.
(3) 3 " " " " " " " " 5 times the usual rate.
(4) 3 " " " " " " " " 10 " " " "
(5) 3 " " " " " " " " 30 " " " "
(6) 4 marled plots with seed treated with culture at the usual rate.
(7) 4 plots, to which inoculating soil had been applied, with untreated seed.

On both fields a good stand was secured on all plots, but on account of continuous cool weather growth was slow and at the close of the season the plants were all very small; and on the Erickson field the differences between very differently treated plots were comparatively small. On the plots on the Swanson field that were treated with marl or soil the growth was much like that on the Erickson field, but on the other plots it was distinctly poorer. The hydrogen-ion concentrations, expressed as pH, on three control plots on the former, sampled in November, were 5.5, 5.4, and 5.3; and on four on the latter, 5.7, 5.5, 5.4, and 5.4 (Table III).

At the end of October samples were taken from more than half the plots on the two fields. The data are reported in Tables XXIV and XXV. On neither field was the number of plants distinctly increased by any of the treatments, but the proportion of those with nodules was much influenced, and in the same way and to much the same extent on both fields (Table XXVI). On the Erickson field the average weight per plant showed no distinct effect of the treatment on either the inoculated or the uninoculated plants, which were similar, but on the less productive Swanson field the uninoculated plants were only about half as heavy as the inoculated, which were alike with all the treatments.

TABLE XXIV

EFFECT OF TREATMENT OF SOIL AND SEED ON STAND, NODULATION, AND WEIGHT OF ALFALFA

Erickson West field at Coon Creek. Sown August 13, 1926; plants examined during latter half of October.

Plot	No. of plants			Nodulation	Weight of plants		Average weight per plant		
	Inoculated	Uninoculated	Total		Inoculated	Uninoculated	Inoculated	Uninoculated	Ratio inoculated to uninoculated
				per cent	grams	grams	grams	grams	
No application to plot; seed not treated.									
B-3	1	87	88	1	0.02	3.97	0.020	0.046	0.4
B-10	3	90	93	3	.12	3.80	.040	.042	1.0
C-15	10	107	117	9	.45	7.05	0.45	.066	0.7
D-7	7	54	61	11	.40	3.22	.057	.060	1.0
Average	5	84	89	6	0.25	4.51	0.041	0.053	0.8
No application to plot; seed treated with culture at usual rate.									
B-4	2	80	82	2	0.09	3.77	0.045	0.047	1.0
B-11	7	100	107	7	.58	5.68	0.83	.057	1.4
C-16	1	67	68	1	.10	4.59	.100	.068	1.5
Average	3	82	86	3	0.26	4.68	0.076	0.057	1.3
No application to plot; seed treated with same culture at 30 times the usual rate.									
B-14	4	59	63	6	0.18	4.25	0.045	0.072	0.6
C-12	7	48	55	13	...	2.95	...	.061	..
D-3	21	61	82	25	...	3.20	...	.052	..
Average	11	56	67	16	...	3.17	...	0.062	..
No application to plot; seed mixed with inoculating soil (1:4)									
C-7	33	86	119	28	2.43	4.30	0.074	0.050	1.5
B-9	21	73	94	22	1.34	4.74	.064	.065	1.0
D-5	40	60	100	40	2.10	3.09	.052	.051	1.0
B-16	16	70	86	19	1.23	4.40	.077	.063	1.2
Average	27	72	100	27	1.77	4.13	0.067	0.057	1.2

TABLE XXIV—*Continued*

Plot	No. of plants			Nodulation	Weight of plants		Average weight per plant		
	Inoculated	Uninoculated	Total		Inoculated	Uninoculated	Inoculated	Uninoculated	Ratio inoculated
				per cent	grams	grams	grams	grams	to uninoculated
				Two tons per acre inoculating soil; seed not treated.					
B-15	65	15	80	81	4.85	1.38	0.075	0.092	0.7
C-13	55	21	76	72	5.19	1.24	.094	.059	1.6
D-4	82	15	97	85	6.66	0.74	.081	.050	1.6
D-12	109	36	145	75	8.34	1.99	.076	.055	1.2
Average	78	22	100	78	6.26	1.34	0.082	0.064	1.3
				Three tons per acre marl; seed treated with culture at usual rate.					
D-19	80	5	85	94	5.53	0.26	0.069	0.052	1.3
B-2	112	6	118	95	9.30	.18	.083	.030	2.8
B-19	70	1	71	99	7.26	.09	.104	.090	1.1
Average	87	4	91	96	7.36	0.18	0.085	0.057	1.7
				Three tons per acre marl; seed mixed with inoculating soil (1:4).					
D-14	104	41	145	72	6.62	2.46	0.064	0.060	1.1
D-6	116	17	133	87	10.91	0.82	.094	.048	1.9
C-2	75	3	78	96	6.55	0.18	.087	.060	1.5
Average	98	20	119	85	8.03	1.15	0.082	0.056	1.5

TABLE XXV

EFFECT OF TREATMENT OF SOIL AND SEED ON STAND, NODULATION, AND WEIGHT OF ALFALFA

Swanson Field at Coon Creek. Sown August 12, 1926; plants examined during latter half of October.

Plot	No. of plants			Nodulation	Weight of plants		Average weight per plant		
	Inoculated	Uninoculated	Total		Inoculated	Uninoculated	Inoculated	Uninoculated	Ratio inoculated to uninoculated
				per cent	grams	grams	grams	grams	
No application to plot; seed not treated.									
2-B	9	101	110	8	0.35	2.40	.039	.024	1.6
4-A	6	94	100	6	.39	4.23	.065	.045	1.4
4-C	4	61	65	6	.20	1.72	.050	.028	1.8
7-B	16	75	91	17	.65	1.87	.040	.025	1.6
Average	9	83	92	9	0.40	2.50	0.049	0.030	1.6
No application to plot; seed treated with culture at usual rate.									
2-C	5	75	80	6	0.29	3.11	0.058	0.041	1.4
5-A	6	100	106	6	.17	3.20	.028	.032	0.7
8-B	8	105	113	7	.23	2.92	.029	.028	1.0
Average	6	93	99	6	0.23	3.11	0.038	0.033	1.1
No application to plot; seed treated with same culture at 30 times the usual rate.									
3-C	3	80	83	4	0.14	2.45	0.046	0.030	1.5
7-A	21	70	91	23	0.84	1.50	.040	.020	2.0
9-B	17	60	77	22	1.01	1.60	.060	.027	2.2
Average	14	70	84	16	0.66	1.85	0.049	0.026	1.9
Two tons per acre of inoculating soil; seed not treated.									
2-A	110	17	127	87	5.35	0.53	0.048	0.031	1.5
4-B	54	20	74	73	3.35	.75	.062	.037	1.7
7-C	95	26	121	78	4.63	.80	.049	.030	1.6
Average	86	21	107	79	4.44	0.69	0.053	0.038	1.6
Four tons per acre of inoculating soil; seed not treated.									
9-C	120	12	132	91	7.95	0.38	0.066	0.031	2.1
Three tons per acre of marl; seed treated with culture at usual rate.									
6-A	66	7	73	90	3.70	0.51	0.056	0.073	0.8
8-A	52	20	72	72	2.64	.47	.051	.023	2.2
6-C	68	20	88	77	3.81	.50	.056	.025	2.2
Average	62	16	78	80	3.38	0.49	0.054	0.040	1.7

TABLE XXVI

EFFECT OF TREATMENT OF SOIL AND SEED ON PROPORTION OF ALFALFA PLANTS WITH NODULES

Application to soil and rate per acre	Treatment of seed	Percentage of plants with nodules		
		Erickson field	Swanson field	Average
None	None	1, 3, 9, 11	8, 6, 6, 17	8
None	Culture at usual rate	2, 7, 1	6, 6, 7	5
None	Culture at 30 times usual rate	6, 13, 25	3, 23, 22	15
None	Four times its weight of soil	19, 22, 28, 40		27
Marl, 3 tons	do	72, 87, 96		85
Marl, 3 to 4 tons	Culture at usual rate	94, 95, 99	90, 72, 77	88
Soil, 2 tons	None	72, 75, 81, 85	73, 78, 87	79

The nitrogen content was determined in the two groups of plants from each of the different treatments, there not being enough from some of the individual plots for a satisfactory determination (Table XXVII). With each treatment the nitrogen was higher in the inoculated plants but the difference was negligible on the plots given neither soil nor marl. When the nitrogen content of the plants from the different treatments is compared, taking the weighted average of both inoculated and uninoculated, it will be seen that it was markedly higher on the plots given marl or inoculating soil than on the others and also higher on the Erickson field than on the less productive Swanson field. On both fields the rank in nitrogen content of the plants from a treatment corresponds with the rank on the basis of the proportion of plants with nodules.

TABLE XXVII

NITROGEN CONTENT OF ALFALFA PLANTS, TOPS, AND ROOTS TOGETHER, FROM FIELDS AT COON CREEK SEEDED ON AUGUST 12 AND 13
Plants gathered in October after growth had ceased.

Treatment and rate per acre	Nitrogen content of			Excess of nitrogen in inoculated plants	Rank of plot in order of					
					Nodulation	Percentage of nitrogen in			Difference in nitrogen between inoculated and uninoculated plants	
	Nodulation	Inoculated plants	Uninoculated plants	All plants		Inoculated plants	Uninoculated plants	All plants		
	per cent	per cent	per cent	per cent	per cent					
					Erickson West field					
None	6	3.27	3.21	3.21	0.06	4	5	5	5	4
Culture at usual rate	3	3.28	3.25	3.25	.03	5	4	3	4	5
Culture at 30 times usual rate	16	3.48	3.24	3.29	.24	3	3	4	3	3
Soil, 2 tons per acre	78	3.89	3.30	3.78	.59	2	1	2	2	1
Marl, 3 tons per acre and culture at usual rate	96	3.88	3.48	3.87	0.40	1	2	1	1	2
					Swanson field					
None	9	3.01	2.64	2.69	0.37	4	3	4	4	3
Culture at usual rate	6	...	2.51	...	...	5	..	5	..	..
Culture at 30 times usual rate	16	2.76	2.73	2.74	.03	3	4	2	3	4
Soil, 2 tons per acre	79	3.41	2.73	3.32	0.68	2	2	2	1	2
Marl, 3 tons per acre and culture at usual rate	80	3.64	2.81	3.25	.83	1	1	1	2	1

DISCUSSION

Disturbing Effect of Drouth on Interpretation of Data

The disturbing effect of periods of very dry weather in such experiments on soils of low water-retaining capacity is very evident, hence the yields considered alone may often be insufficient for reliable deductions. When moisture has become such a limiting factor that the plants on plots with full stands begin to dry up before having made normal growth, the plots with poor stands may give heavier yields, either because more moisture was left in the subsoil at the time of the previous cutting, or because, on account of the much smaller number of plants, a smaller proportion of the rain falling was required for maintenance of life. In addition to the yields, a record of the appearance of the crop on the different plots is desirable, as was well illustrated in 1925 and 1926 by the plots on the Anderson field.

Value of Nitrogen Determinations

The determination of the nitrogen content of alfalfa plants is often worth while when there is doubt as to the inoculation, for instance when the investigator can not personally examine the roots, when it is suspected that the nodules may have become detached while the roots were being freed of soil, or when the absence of nodules from inoculated plants might be due to hot, dry weather (7, p. 16). Some possibilities of this analytical procedure were pointed out by one of the authors seventeen years ago (2, p. 4).

The analyses of the hay from the Crow Wing plots (Table XX), even in the absence of any observations on the plants, would leave little doubt as to the inoculation having been as complete on the three control plots as on those given both marl and a heavy application of soil. The lower percentages of nitrogen on the small plants from the 1926 seedings at Bemidji and Coon Creek that carried no nodules, make it evident that there had been no serious detachment of nodules during the process of removing and washing the roots (Tables XXII to XXV).

Distribution of Nodule Bacteria in Manure

It has been suggested above that the anomalous behavior of the alfalfa on the West field at Coon Creek might be due to the previous application of manure from stables where alfalfa hay had been fed freely. The use of similar manure at Backus was mentioned, it appearing to have had little effect there.

There seems to be no definite information as to the extent to which manure from alfalfa-fed animals may supply root-nodule bacteria. Fred, Whiting, and Hastings mention that while the "idea is common that if the hay from a well inoculated field is fed to stock and the

manure distributed on other fields the root nodule bacteria will be carried in this manure," experiments of one of them show that the bacteria in the hay that passes the digestive tract are destroyed (7, p. 37). They recognize, however, that some of the small particles of soil mixed with the hay will become mixed with the manure without passing through the animals and so cause a slight distribution of the desired bacteria. The more liberal is the feeding of the hay the more chance there is of the manure thus becoming well supplied with the bacteria.

In 1903 one of the authors examined a newly sown field of alfalfa on the crest of a ridge near Kearney, Nebraska, in which no uninoculated plants were found. The only explanation that appeared reasonable was that the bacteria had been distributed along with the manure taken from stables where the cattle were fed very liberally with alfalfa hay from large fields in the valley in which all the plants examined were found well inoculated (1, p. 14). A light application of the manure had been made in advance of seeding for this very purpose. The full inoculation later found in fields in other parts of Nebraska seemed best explained in the same manner and the matter was discussed briefly in 1910 (1, p. 19). The same explanation appears to apply on some Minnesota fine-textured soils that are not lime deficient.

In drawing conclusions from Nebraska observations to apply to sandy areas in Minnesota, it should be pointed out that the soils of the important Nebraska alfalfa districts are naturally well supplied with lime and that the alfalfa hay was usually fed so liberally that a considerable part of it did not pass through the animals. There are neither observations nor experiments contributing satisfactory evidence in support of such a practice as a means of inoculation on the lime-deficient sands of Minnesota.

Relative Effectiveness of Different Methods of Inoculation

The quality of the two commercial cultures used appears above criticism, no evidence of incomplete inoculation having been observed when the alfalfa or sweet clover was sown on land to which ground limestone, hydrated lime, or marl had been applied some time in advance. In the few cases where it was evident that inoculation was incomplete, the seed had been sown very soon after an application of ground limestone. On the sand experimental fields alone, during the eight seasons under consideration, more than 200 seedings of alfalfa, with the one or the other of these cultures as the only inoculant, were made on land that had never before been seeded to alfalfa or sweet clover, and to which there had been no application of manure from stables where either of these legumes was being fed. These seedings were either on limed plots only or on groups of plots the most of which had been limed.

The effectiveness of the previous growing of alfalfa or sweet clover on such lime-deficient soil is well shown in the case of two of the seedings on Series A at Coon Creek—the 1921 seeding after sweet clover and the 1924 seeding after plowing under alfalfa (Figs. 4 and 9). The experiments furnish no evidence as to whether sweet clover is more effective than alfalfa, as is quite commonly believed. Russell mentions "a recent indication that the growth of one leguminous crop may intensify the infection of a subsequent crop; the inoculation of lucerne is said to be rendered more secure by first growing *Melilotus alba* and the plowing it under before the lucerne is sown" (16, p. 78).

The plowing under of both sweet clover and alfalfa in fresh condition on the Bemidji field failed to increase the proportion of inoculated plants. Evidently the beneficial action of these crops is due to something developed in or imparted to the soil while they are growing, and it might be as great if both roots and tops were entirely removed before the second seeding. Such being the case the advantage of plowing would lie simply in the preparation of a better seedbed and the destruction of weeds.

Some American farmers have been practicing what is known as the "gradual method" of inoculation. On fields on which they wish to make sure of a stand of alfalfa, they seed sweet clover with the grain crops, or add a pound or two of alfalfa seed to the ordinary grass mixtures.

Inoculating soil was found far more effective than cultures on unlimed land and observations indicate that the application of soil from a well established alfalfa or sweet clover field is as effective on new seedings as the previous growth of one of these legumes. The amount of soil required for the maximum effect is uncertain, the experiment on the Backus field indicating that with the soil used there the benefit increased with the amount of soil applied, up to 2 tons per acre, while in the experiment on the Erickson South field at Coon Creek ½ ton appeared as effective as 2 tons. The results on the Erickson West field suggest that a small amount of the soil is much more effective when mixed with the seed than when worked into the seedbed, but that for full inoculation, four times as much soil as seed is insufficient on such lime-deficient soils.

The experiments furnish no evidence as to whether inoculating soil loses in effectiveness when applied some time in advance of seeding, or as to whether soil from a sweet clover field is more effective than that from an alfalfa field. Soil from unlimed land on which one of these legumes is well established might be expected to be preferable if the superiority of the soil were due to more virulent strains of bacteria, but the results of the Bemidji experiment rather favor the use of soil from limed land.

What little experimental evidence there is suggests that the difference in efficiency between the soil transfer and pure culture methods increases with the acidity of the soil. On none of the experimental fields under consideration does the unlimed soil appear too acid to permit of the establishment of successful stands of alfalfa, without liming, provided sufficient inoculating soil be used. It is not improbable that the transfer of soil without liming would prove inadequate on most sandy soils having a higher hydrogen-ion concentration than the most acid of those dealt with here.

In some of the Coon Creek fields there is, within a few feet of the surface, a substratum much less acid than the surface soil (Table II). This does not appear necessary in order that the use of inoculating soil may suffice for the production of satisfactory yields of alfalfa on fields in which the surface soil is lime deficient. The recovery of alfalfa on unlimed control plots on one of the Minnesota experimental fields with clay loam soil and subsoil has recently been described in detail and attributed to the roots getting down to the calcareous subsoil (3, p. 26).

If a beneficial effect of the soil, when used in addition to a pure culture, were found only when it was taken from limed land it might be suggested that the small lumps, granules, or grains of this limed soil, mixed with the surface few inches of a field just sown, would furnish just so many favorable *loci* for both the nodule bacteria that the soil particles might carry and those adhering to such of the treated seeds as came into contact with them. If the benefit of inoculating soil were thus due simply to its favorable reaction, a similar beneficial effect might be expected when the soil applied was taken from limed land upon which neither alfalfa nor sweet clover had been grown. Also, a different explanation would be required for the effect of the previous growing of alfalfa or sweet clover on unlimed land. It is of interest in this connection that in the Bemidji experiment, soil taken from unlimed land on which sweet clover was growing showed a markedly beneficial effect.

The superiority of the soil applications does not appear due to their supplying a greater number of bacteria per seed, because, if such were the case, the proportion of plants with nodules should have been greatly increased on the plots on the Swanson and West Erickson fields on which the culture was used at 30 times the usual rate. On those fields the proportion of plants on which nodules were found nine weeks after seeding was no higher where 2 tons per acre of inoculating soil had been applied than where a culture at only the usual rate was used on marled plots. On the latter it was many times as high as on the unlimed plots on which the culture had been used at 30 times the usual

rate. From this it appears that with a favorable soil reaction a culture used at the usual rate furnishes enough organisms fully to inoculate the plants.

Probable Cause of Superiority of Soil

Russell mentions the failure, hitherto, of attempts to "isolate and use more virulent strains (of alfalfa nodule bacteria) than those normally occurring in the soils" (16, p. 78). The recent work of Fred, Whiting, and Hastings (7, p. 20-21) appears to increase the probability of the greater potency of the soils being due to their furnishing more virulent strains of the organism, altho these authors do not mention any superiority of soils as inoculants. Using eight strains of nodule bacteria of the alfalfa group, four from each of two serological groups, A and B, they compared their behavior, in jars of quartz sand, in relation to the total amount of nitrogen assimilated, number of nodules, and position of the nodules on the roots. The plants treated with the strains of Group A were darker, taller, and contained much more nitrogen than the plants treated with the strains of Group B. With the former the nodules were large and located chiefly within the first few inches of sand, while with the latter they were much smaller, much more numerous, and located in all parts of the root system.

From the Rothamsted investigations referred to above, however, it seems not improbable that the superiority of the soil may be due to its presenting the organism to the alfalfa rootlet in a different form. Thornton emphasizes the importance of the exact method used in applying the bacteria to the seed. "During certain stages in their life cycle they are actively motile and, in this condition, are able to migrate through the soil. When inoculated seed is sown the bacteria have to pass through the soil to reach the various parts of the root system where the nodules are produced. The timely appearance of the motile forms in the soil is thus of vital importance. The nature of the fluid used to convey the bacteria to the soil influences both the time of appearance and the relative numbers of these motile stages. It produces a corresponding influence on the migration of the bacteria through the soil. For example, when a suspension of the bacteria in water was added to the soil it took three days before they began to spread away from the point of inoculation. When a suspension in milk was added, the initial rest-period was reduced to forty-eight hours, while from a suspension in milk and calcium phosphate the bacteria began to spread after twelve hours. The addition of calcium phosphate to the milk thus stimulates the bacteria to migrate through the soil and increases the volume of soil infected by them in a given time" (18, p. 7-8).

No reports of other experiments with this method have so far appeared, but it was used by English farmers last season, papers with the

proper amounts of calcium phosphate being sent out by the Rothamsted Experimental Station with the tubes of pure culture. This method has not been tried on the Minnesota fields, it having come to the attention of the authors only in October, 1926, and Thornton and Gangulee's paper was not available until after the ground was solidly frozen.

Bewley and Hutchinson (1920) found, in comparisons of pure cultures with soils as inoculants, that the latter were almost invariably the more effective and suggested that part of this superiority may be due to the form in which the organism is presented to the host plant, their investigations having shown "that soil is instrumental in the formation of the pre-swarmer form, and this might be expected to make for an earlier or more effective infection of the plant" (4, p. 160). Finding that a small amount of calcium phosphate was very effective in the production of motile forms, they suggested that "the effect of phosphate in converting pre-swarmers into swarmers might be expected to facilitate infection" (4, p. 159).

Studying the effect of various liquid media on the predominance of the different forms of the alfalfa nodule organism, Gangulee observed that soil extract induced the motile stage earlier than any of the other liquid media tested in the experiment (8, p. 363). Following up the work of Bewley and Hutchinson, and using pots filled with a mixture of soil and sand, Thornton and Gangulee found that the addition of as little as 0.1 per cent $CaH_4(PO_4)_2+H_2O$ to the milk used to bring the pure culture into suspension greatly affected the nodule formation for at least 16 weeks after seeding. "The addition of calcium phosphate produces no increase in nodules in the top four inches of the root, near the point of inoculation. There is consequently no effect from the phosphate until the sixth week, when the root system begins to develop to this depth. From this time onwards the phosphate produces an increase in nodule numbers, which, however, is entirely confined to the distal region of the root system. The effect of the phosphate consequently becomes more marked as the plant grows older and the lower roots develop" (19, p. 447-8). While they do not report similar experiments with soil or soil extract, it might be expected from the earlier observations of Gangulee that these would have a similar effect.

It does not appear that the addition of phosphate to the soil in advance of seeding alfalfa induces any such effect as its addition to the medium in which the bacteria are suspended. It is of interest to note that on none of the various seedings on Series A, B, C, and D on the South field at Coon Creek has the stand or growth of alfalfa on the phosphate-fertilized plots (Fig. 2) been superior to that on the controls. On the other sand experimental fields, phosphate fertilizers have been used only on limed plots.

It is an open question whether the superiority of the inoculating soil on these lime-deficient sandy fields is due to its carrying strains of bacteria more tolerant of the acid soils than are those of the pure cultures; or to its presenting the organisms in a more active form; or to the presence in it of a minute quantity of a very potent chemical compound which either has a profound and prolonged effect upon the bacteria or serves to counteract some toxic substance in the soil or to still some other cause.

The difficulty of securing inoculation of alfalfa or sweet clover on such unlimed soils, when pure cultures are used, leads to confusion in interpreting results of liming experiments, where these legumes are employed as the trial crops. The beneficial effect of the liming may be due much more to its influence on the early inoculation, and hence on the survival of a sufficient proportion of the plants, than upon their subsequent growth. Such confusion can be avoided by the use of a liberal application of inoculating soil on all the plots under comparison until more potent pure cultures or improved methods of using the present ones render this no longer necessary.

LITERATURE CITED

1. Alway, F. J. The importance of the inoculation of alfalfa on Nebraska upland soils. Ann. Rept. Neb. Agr. Exp. Sta., 1909:3-20. 1910.
2. ——— and Pinckney, R. M. The nitrogen content of inoculated and uninoculated alfalfa plants. Ann. Rept. Neb. Agr. Exp. Sta., 1909; 33-34. 1910.
3. ——— and Rost, C. O. Liming for alfalfa in southeastern Minnesota. Minn. Agr. Ext. Special Bull. 107. 32 pp. 1926.
4. Bewley, W. F., and Hutchinson, H. B. On the changes through which the nodule organism (*Ps. Radicicola*) passes under cultural conditions. Jour. Agr. Sci. 10:144-162. 1920.
5. Cox, H. A. How to inoculate legumes. N. J. Agr. Exp. Sta. Ext. Bull. 32, 4 pp. 1923.
6. Duggar, J. F. Soil inoculation for leguminous plants. Ala. Agr. Exp. Sta. Bull. 87, 30 p. 1897.
7. Fred, E. B., Whiting, A. L., and Hastings, E. G. Root nodule bacteria of *Leguminosae*. Wis. Agr. Exp. Sta. Research Bull. 72, 43 pp. 1926.
8. Gangulee, N. Studies on the lucerne nodule organism (*B. Radicicola*) under laboratory conditions. Ann. App. Biol. 13:360-373. 1926.
9. Kellerman, R. F. The present status of soil inoculation. Centralb. für Bakt. 34:42-46. 1912.
10. ——— and Robinson, T. R. Inoculation of legumes. U. S. Dept. Agr. Farm. Bull. 240, 7 pp. 1908.
11. ——— and ———. Conditions affecting legume inoculation. U. S. Dept. Agr. Bur. of Pl. Indust. Bull. 100:73 80. 1907.
12. ——— and ———. Progress in legume inoculation. U. S. Dept. Agr. Farm. Bull. 315, 20 pp. 1908.

13. Löhnis and Fred, E. B. Textbook of agricultural bacteriology. 283 pp. New York. 1923.
14. Oakley, R. A. How to grow alfalfa. U. S. Dept. Agr. Farm. Bull. 1283. 35 pp. 1922.
15. Russell, E. J. The spread of lucerne growing. The growing of lucerne, being the report of a conference held at Rothamsted on January 27, 1926. 32 pp. London. 1926.
16. ———. Plant nutrition and crop production. 115 pp. Berkeley, Calif. 1926.
17. Stewart, G. Alfalfa growing in the United States and Canada. 517 pp. New York. 1926.
18. Thornton, W. G. Lucerne inoculation trials. pp. 7-10. The growing of lucerne. 32 pp. London. 1926.
19. ——— and Gangulee, N. The life cycle of the nodule organism *Bacillus radicicola* (Beij.) in soil and its relation to the infection of the host plant. Proc. Roy. Soc., **B.99**:427-451. 1926.

Technical Bulletin 47 July 1927

University of Minnesota
Agricultural Experiment Station

An Analysis of the Cost of Tile Drainage Installation on the Farm

By H. B. Roe
Division of Agricultural Engineering

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	5
Scope of the investigations	5
Classification of projects according to character of surface	5
Drainage projects involved	5
Elements of cost, with definitions	17
Classification according to drainage character of the land	18
Actual money costs of projects	18
Percentages of total cost represented by each element	18
Basic units	18
The time factor	19
Cost of each element	19
Engineering and supervision	19
Tile	19
Freight on tile	20
Haul and distribution	20
Trenching, laying, and blinding	21
Balanced cost schedule for tile trenching	21
General considerations	21
Character of digging	21
Limiting sizes of tile and depths of trench	22
Time factor	23
Reasonable maximum error in estimated time and resultant work units	23
Character of Tables XVI, XVII, and XVIII	23
Method of procedure	23
Fixing upon a work unit	23
General assumptions	24
Method of computation of Tables XIX and XX	26
Statement of formulas used in computing Table XIX from Fig. 19b	29
Method of computation of final schedules	30
Reliability of trenching schedules	31
Practical illustration of the use of trenching schedules	31
Refilling trenches	32
Outlet protection and miscellaneous	34
Practical illustrations of the use of the tables of cost data	34
Assumed details	34
Illustration of a fairly exact method such as an engineer would be likely to use	34
Illustration of approximate short method such as a farmer might use	37
Illustration of handy method for the contractor	37
Illustration of handy method for the manufacturer	37
Special conditions not covered	38
Acknowledgments	38

ILLUSTRATIONS

		Page
Figs. 1 to 18.	Outline maps of the separate projects	6-16
19a.	Typical cross-section of spoil bank and tile trench for tile less than 10 inches in diameter	28
19b.	Typical cross-section of spoil bank and tile trench for tile 10 inches in diameter and larger	28
20.	Curves showing the data in Table XX (work units per linear foot of trench for given sizes of tile and depths of trench	65
21.	Curves showing the data in Table XXI (hours required to dig 100 linear feet of trench for given sizes of tile and depths of trench) (easy digging)	66
22.	Curves showing the data in Table XXII (hours required to dig 100 linear feet of trench for given sizes of tile and depths of trench) (average digging)	67
23.	Curves showing the data in Table XXIII (hours required to dig 100 linear feet of trench for given sizes of tile and depths of trench) (hard digging)	69
24.	Curves showing the data in Fig. XXVI (hour units of one team hour plus one and one-third man hours required to refill 100 linear feet of trench for given sizes of tile and depths of trench	75

TABLES

		Page
I.	General descriptions of farm projects involved	39
II.	Areas of individual projects, in acres	41
III.	Total costs and costs per acre per project (in dollars)	43
IV.	Cost of each element in dollars per project and per cent that each element represents of the total cost	44
V.	Time in hours for labor items for each project and for all projects	46
VI.	Engineering and supervision cost in money and in time	48
VII.	Linear feet of different sizes of tile used	51
VIII.	Linear feet of tile used (classified only as over 6-inch, and 6-inch and less)	52
IX.	Weight of tile used, in tons	53
X.	Weight of tile used, in carloads of 30,000 lbs	54
XI.	Money cost of tile	55
XII.	Carloads and tons of tile, miles of railroad and of team or truck haul, carload-miles of railroad haul and ton-miles of team or truck haul	56
XIII.	Money cost of freight on tile	57
XIV.	Cost in money and in time of haul and in distribution of tile	58
XV.	Cost in money and in time of trenching laying and blinding	60
XVI, XVII, and XVIII.	Work units, man hours, size of tile, and average cut for all projects *in easy digging, in average digging,* and *in hard digging,* respectively	61, 62, 64

TABLES—*Continued*

Pa

XIX. Factors entering into computation of work units per linear foot of trench

XX. Work units per linear foot of trench for given size of tile and depths of trench.....

XXI, XXII, and XXIII. Hours required to dig 100 linear feet of trench for given sizes of tile and depths of trench *in easy digging, in average digging,* and *in hard digging,* respectively.....66, 67,

XXIV. Cost in money and in time of refilling trenches, per hour unit, per acre, and per 1000 linear feet, per ton, and per carload of tile.....

XXV. Areas and volumes of trenches for sizes of tile used and average depths of trench therefor.....

XXVI. Hour units required to fill 100 linear feet of trench for given sizes of tile and depths of trench.....

XXVII. Cost of outlet protection in money and in time.....

XXVIII. Cost of miscellaneous in money and in time.....

XXIX. Average cuts from hubs for given sizes of tile.....

XXX. Average sizes of tile and average rates of grade.....

XXXI. Approximate weights per linear foot of standard sizes of tile.....

AN ANALYSIS OF THE COST OF TILE DRAINAGE INSTALLATION ON THE FARM

By H. B. Roe

INTRODUCTION

As drainage is a large and important problem in agriculture in Minnesota, and as very little definite knowledge regarding its cost on the individual farm has been developed elsewhere, extensive investigations of methods of installation and costs of tile drainage have been carried out by the Division of Agricultural Engineering, of the Experiment Station. The result is a mass of data on costs which are herein analyzed and presented in a form readily available for use.

SCOPE OF THE INVESTIGATIONS

Classification of Projects According to Character of Surface

The investigations on which this bulletin is based were carried on from 1908 to 1921, inclusive. The areas involved fall naturally into three principal classes: rolling land, flat land, and peat land. The purpose of the investigations was to separate the costs into their fundamental elements and to determine suitable and balanced cost units for each element for each class of land. The aim has been to keep these units as independent as possible of local and temporary economic influences and conditions.

Drainage Projects Involved

The actual farm drainage projects serving as a basis for this discussion are listed in Table I, page 39, which gives the number, location, time of installation, and general character of the tract involved in each. The projects have been numbered in the order of the dates of installation, and this order of numbering will be adhered to throughout the bulletin. Figures 1 to 18 show the general layout of the tile systems on the projects.

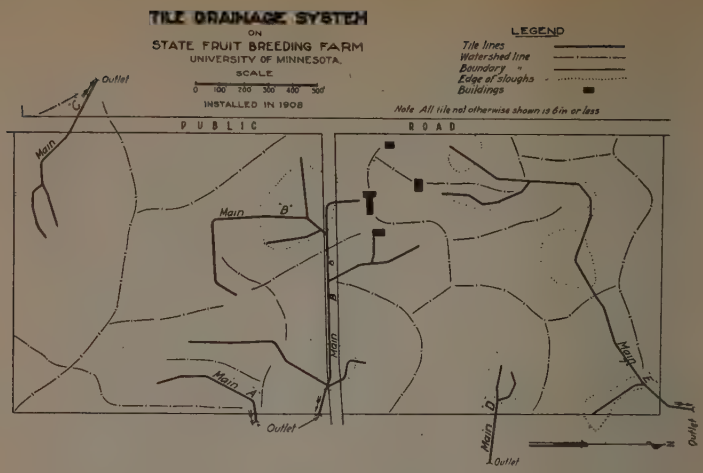


Fig. 1. Project 1. Rolling Land

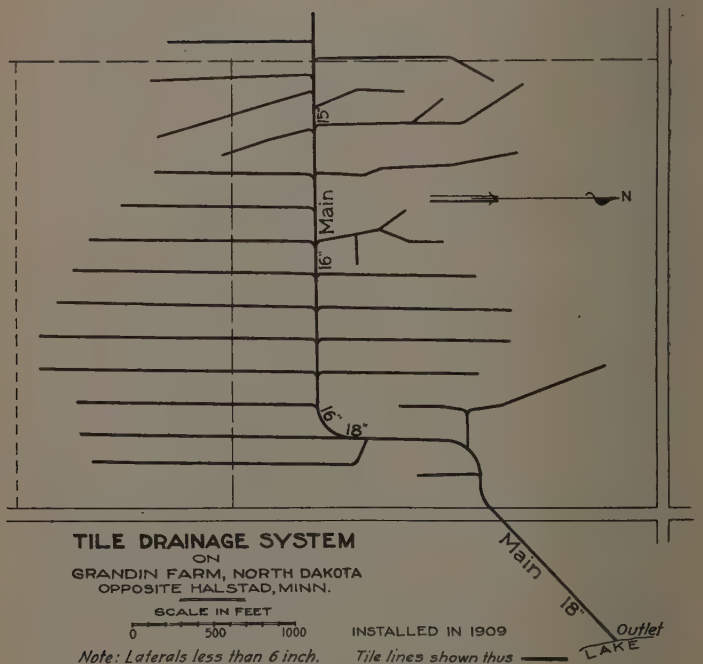


Fig. 2. Project 2. Flat Land

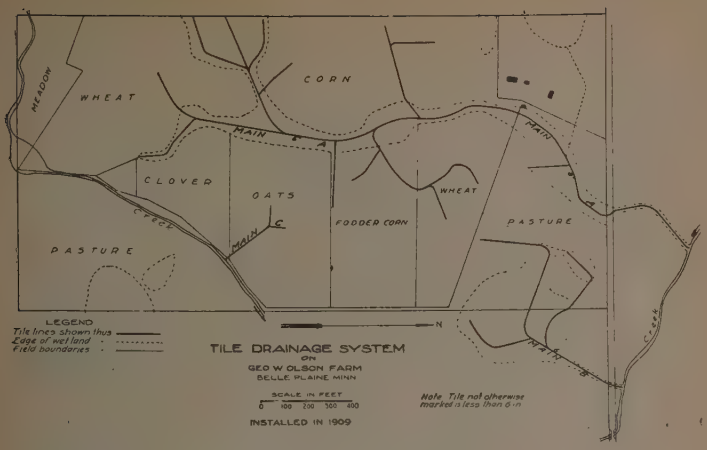


Fig. 3. Project 3. Rolling Land

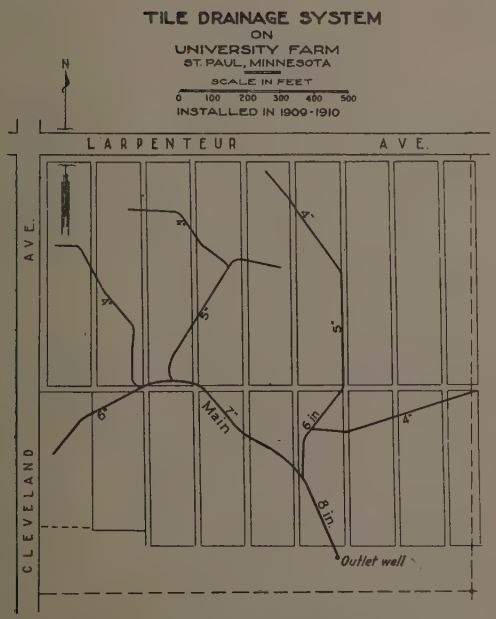


Fig. 4. Project 4. Flat Land

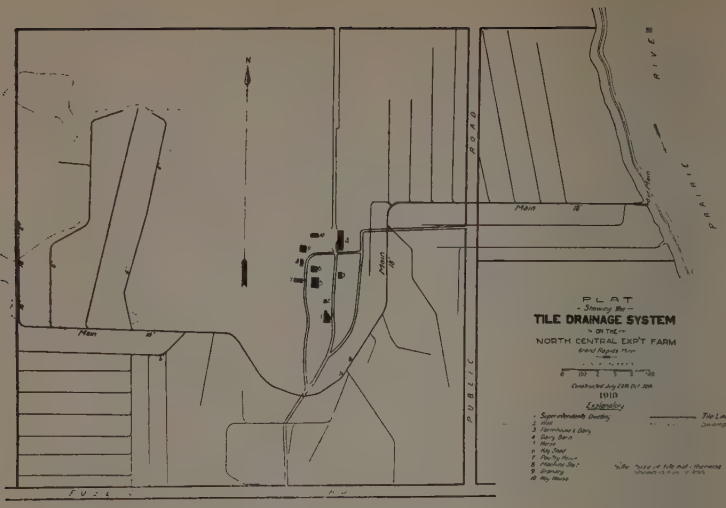


Fig. 5. Project 5. Flat Land

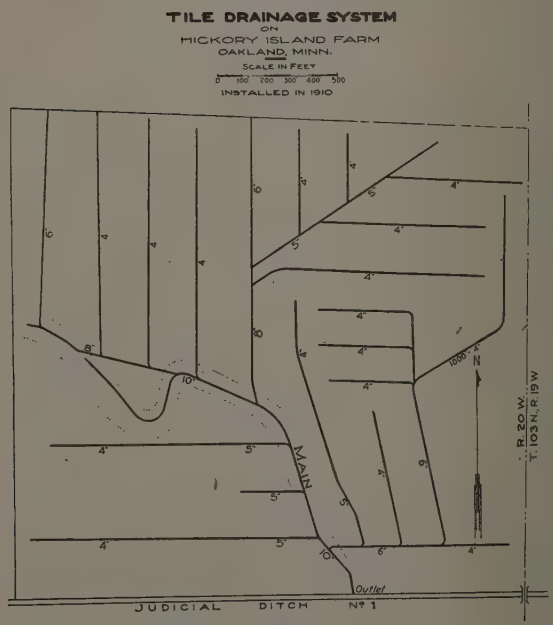


Fig. 6. Project 6. Flat Land

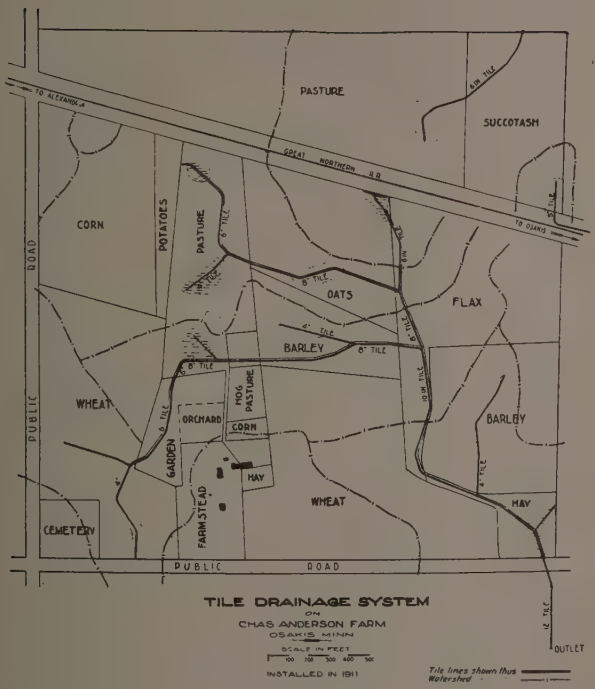


Fig. 7. Project 7. Rolling Land

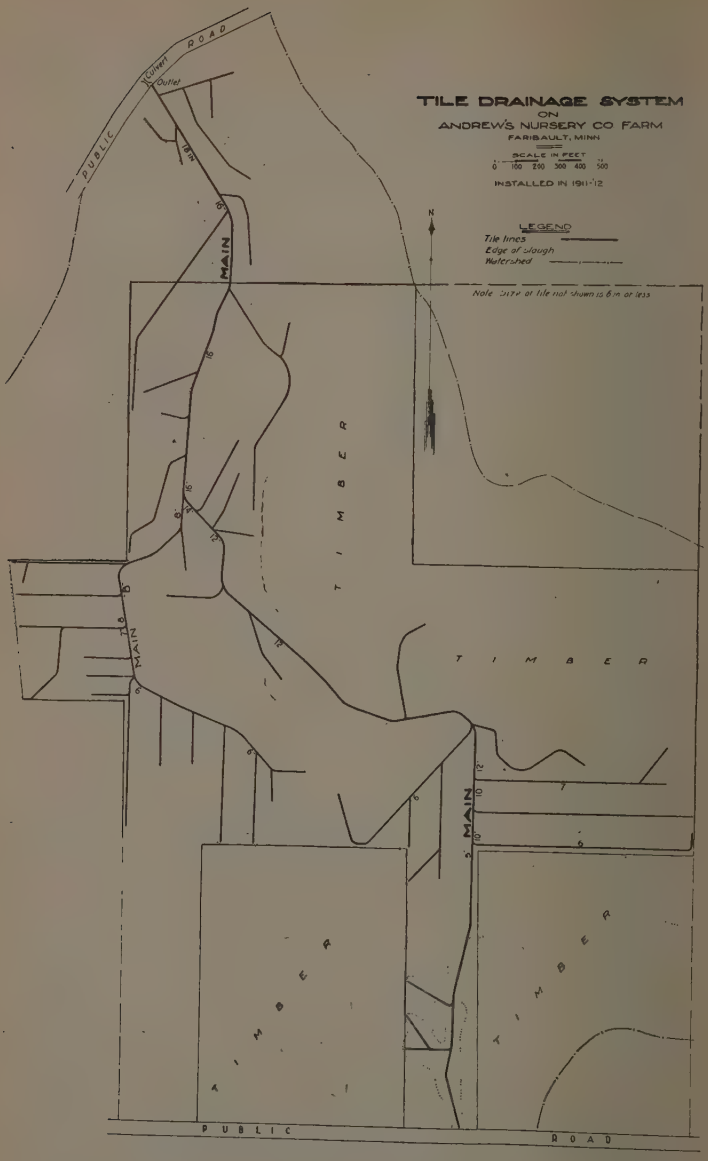


Fig. 8. Project 8. Rolling Land

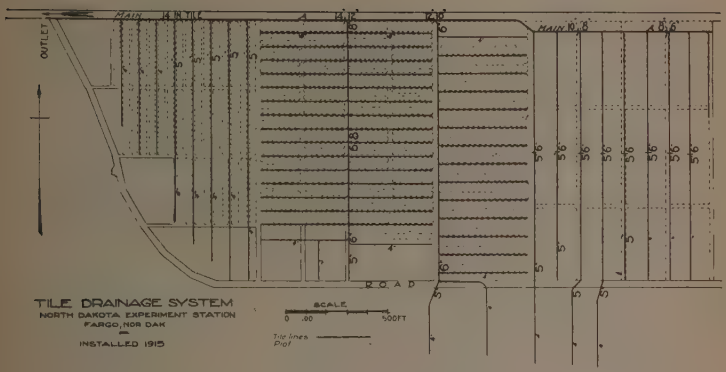


Fig. 9. Project 9. Flat Land

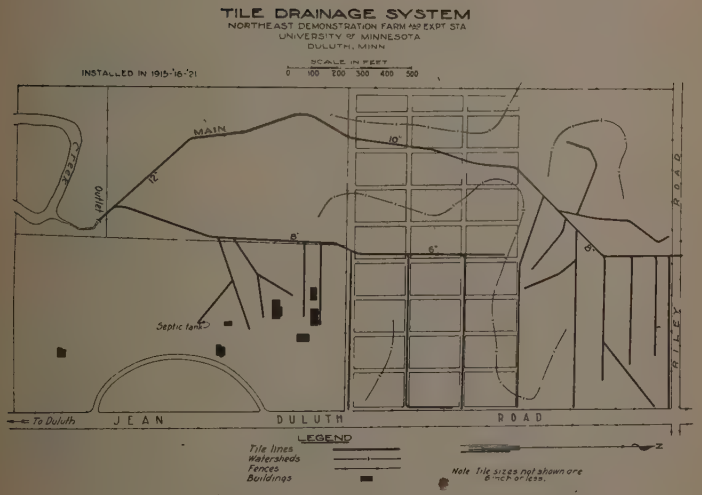


Fig. 10. Project 10. Rolling Land

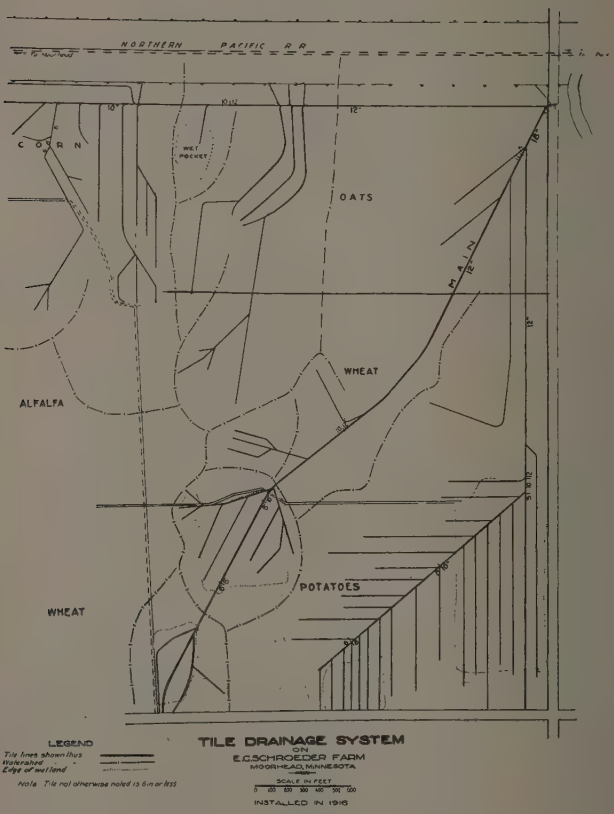


Fig. 11. Project 11. Flat Land

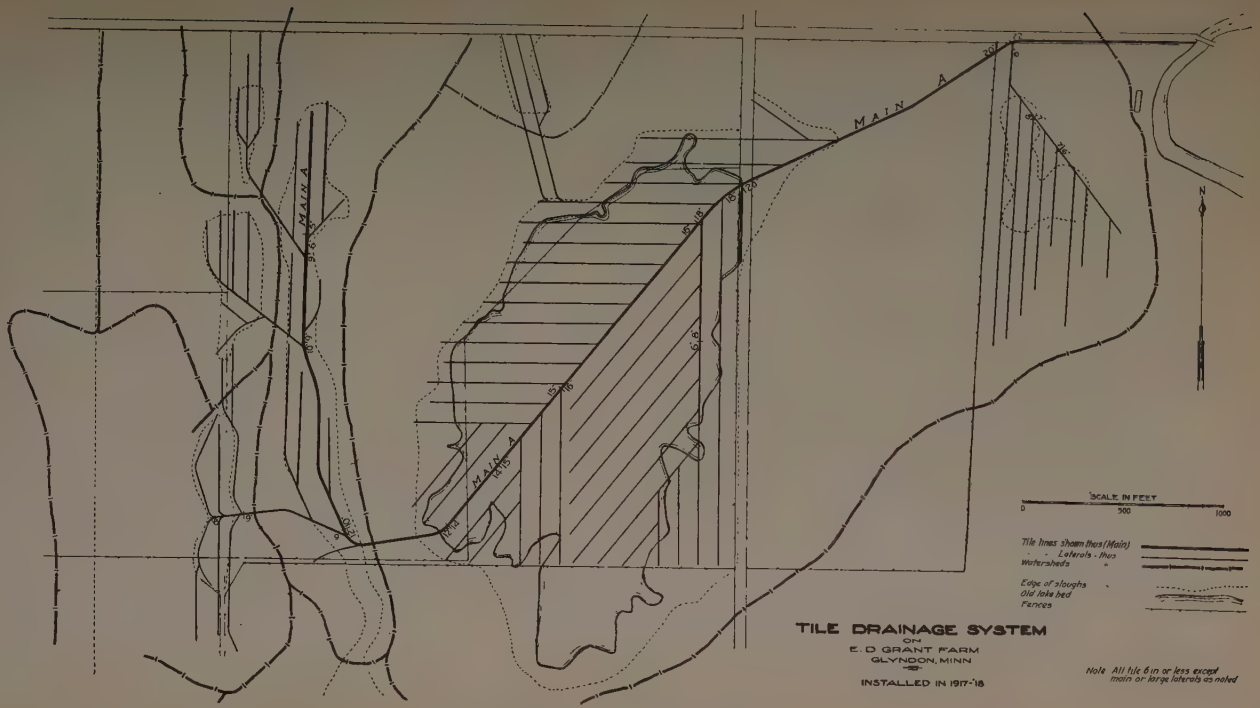


Fig. 12. Project 12. Flat Land

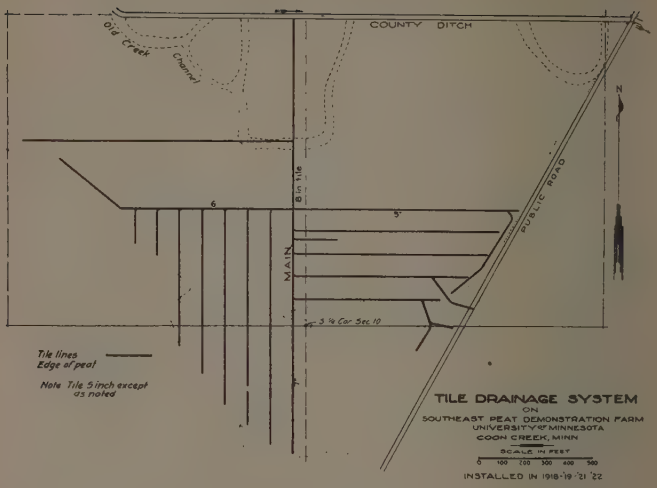


Fig. 13. Project 13. Peat Land

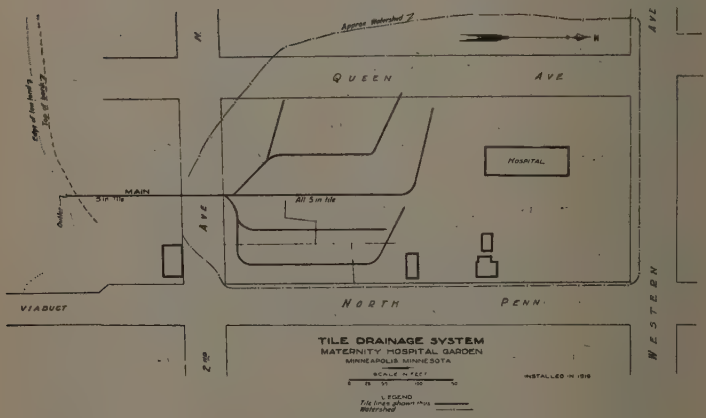


Fig. 14. Project 14. Rolling Land

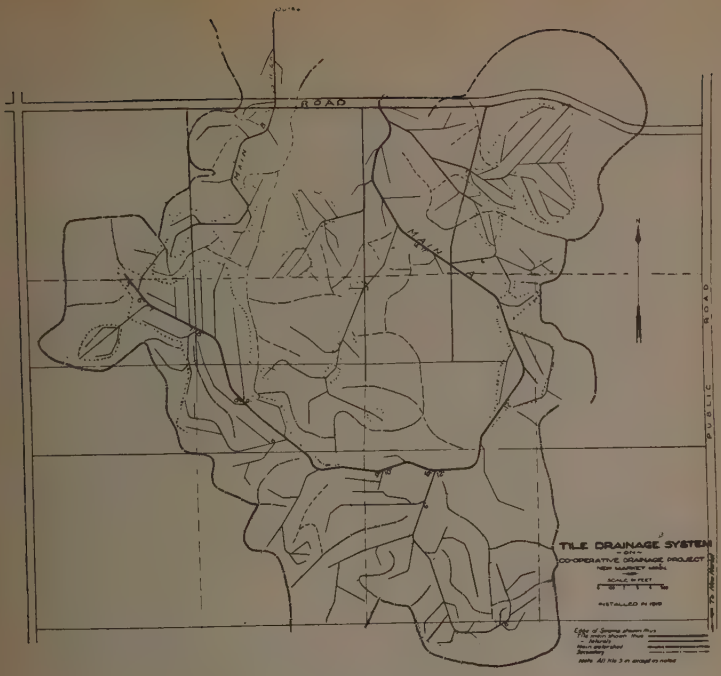


Fig. 15. Project 15. Rolling Land

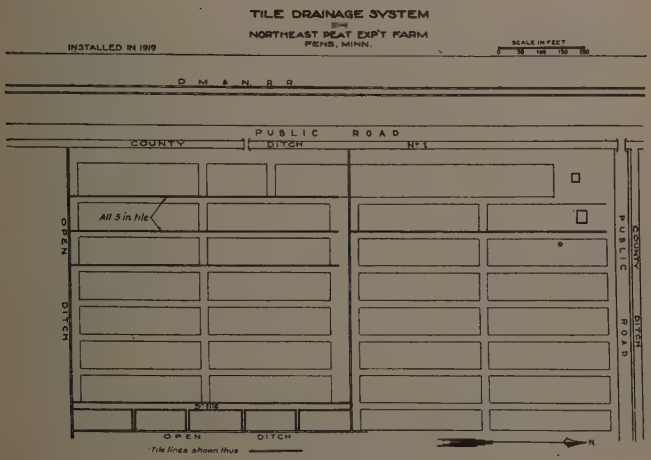


Fig. 16. Project 16. Peat Land

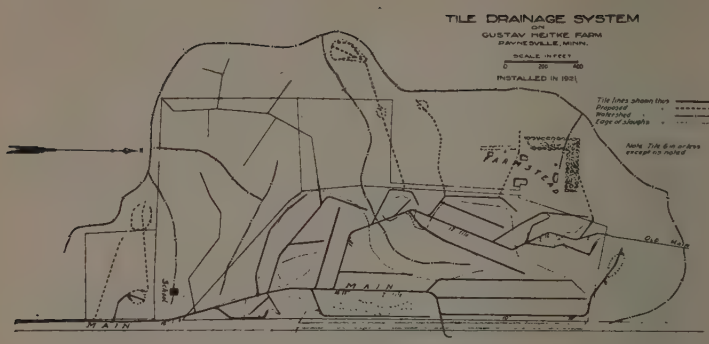


Fig. 17. Project 17. Rolling Land

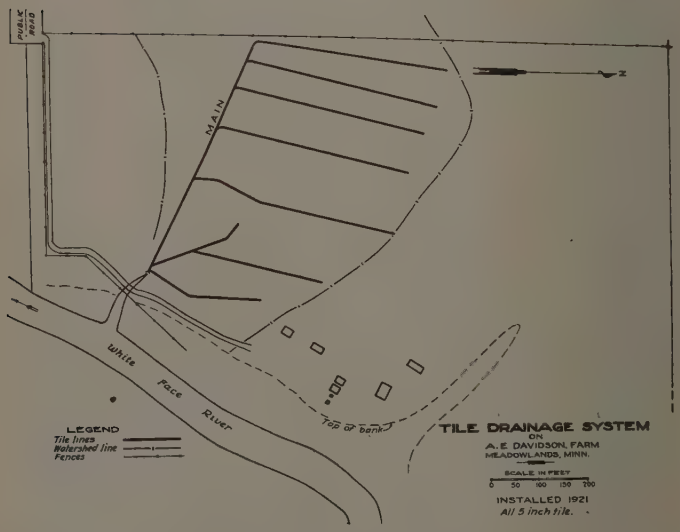


Fig. 18. Project 18. Flat Land

ELEMENTS OF COST, WITH DEFINITIONS

The cost of any ordinary farm tile drainage system is made up of the following distinct elements:

Engineering and supervision
Tile
Freight on tile
Haul and distribution (hauling the tile from the railroad station and distributing it over the fields along the proposed tile lines)
Trenching, laying, and blinding the tile
Refilling trenches
Outlet protection
Miscellaneous minor items

Engineering and supervision includes all work of an engineering character—field survey and design, and engineering supervision and inspection of the construction work, as well as all attendant clerical and drafting-room work.

Tile includes all closed pipe used in the system, both drain tile and sewer pipe, but does not include outlet culverts.

Freight on tile includes the actual railroad freight charges from factory or other point of purchase to destination.

Haul and distribution includes all costs of unloading the tile from the cars; loading it on wagons, sleighs, or trucks; hauling it from the railroad station to the fields; and unloading and distributing it along the drain lines.

Trenching, laying, and blinding includes all work of digging the trenches and finishing them to the grades established by the engineers; laying the tile in the finished trench; and blinding the tile (covering them to a depth of from six inches to a foot to hold them in place and prevent disturbance until the trenches are to be entirely filled). It is customary to consider *trenching, laying, and blinding* as one operation because they are intimately associated in point of time and it is well nigh impossible to separate them. Prices for this work usually include these three taken as a unit.

Refilling trenches includes all work of filling the trenches after the blinding has been done. This class of work is far simpler than the preceding and does not require skilled labor.

Outlet protection includes the labor and materials involved in providing proper protection for the tile outlet against crushing and undermining and against the entrance of birds and animals.

Miscellaneous includes all such items as a limited amount of open ditching at the outlet or in connection with other items; the

installation of catch basins and surface inlets; temporary ditching preceding the regular installation in order to remove surface water and make regular construction work possible; the placing of boards in the bottom of the trenches in soft spots; and minor tools and equipment purchased especially for the project in hand and virtually used up during the job.

CLASSIFICATION ACCORDING TO DRAINAGE CHARACTER OF SURFACE

It is often convenient to consider drainage cost on a per-acre basis and in one of three ways, namely, per acre of water-shed on the farm involved, per drained acre, and per totally reclaimed acre. Therefore, in this analysis, the various units have been worked out on each basis. Table II, page 41, shows the area of each of these classes for each project.

ACTUAL MONEY COSTS OF PROJECTS

As the time covered by these investigations includes periods of widely varying economic conditions, the actual cost of each or any project is not a definite basis for final conclusions, but will be convenient for making comparisons and for working out useful percentages discussed later. The actual total costs of each project and of all projects in each land class, on the acre basis, are shown in Table III, page 43.

PERCENTAGES OF TOTAL COST REPRESENTED BY EACH ELEMENT

It is convenient to know the percentages of the total cost represented by each element, as by their use a fairly close estimate of the cost of any project can be obtained where a tolerably reliable value of any one element is known. While the projects included in these investigations may not give conclusive percentages, still, as they cover a wide range of local conditions, character of surface and soil, the percentages obtained may be fairly representative of farm drainage work in the state, especially when the affected areas are classified according to character of surface. Such percentages, together with corresponding actual costs of each element, are shown in Table IV, page 44.

BASIC UNITS

For general use, independent of time and economic conditions, it is necessary to establish general cost units not expressed in terms of dollars and cents but which are readily reducible to such terms if prevailing values of labor and of certain types of materials are known. The normal basis of all costs involving labor is the hour unit. This

will apply to engineering and supervision costs as well as to the common, labor items, in this discussion. Table V, page 46, shows the total hours of man, horse, and machine labor involved in each element of each project as well as the total time for each element on all projects. These totals are used later in determining average fundamental units of work and average amounts of work done per hour in the different elements.

The Time Factor

The data on time spent on each project are believed to be fairly reliable altho part of the time on some projects is estimated (see Table V). In this respect the projects fall into three classes:

1. Those in which the time record is exact.
2. Those in which part of the time record is exact and the rest is estimated between approximate dates.
3. Those in which the entire time has been estimated, as carefully as possible, between approximate dates.

If the exact time was not known, the time consumed on the different parts of the work was carefully estimated. The estimates were made after careful scrutiny of all available records and after consultation, wherever possible, with others in responsible charge of the work.

It is often desirable to know the cost or the amount of materials or labor required per acre, per thousand feet, per ton, or per minimum carload of tile (30,000 lbs.), hence tables are included showing the money costs, hours of labor, and materials required, distributed on this basis.

COST OF EACH ELEMENT

Engineering and Supervision

Engineering and supervision on drainage work is usually paid for by the day at established professional rates and includes both compensation for service and necessary traveling, subsistence, and special expenses incurred in connection with the work. On most of the projects discussed the engineering and supervision was done by members of the station drainage staff and the compensation in these cases was therefore determined by their annual salaries at the time the work was done. Table VI, page 48, gives the actual cost of this element for each project, the cost per hour, and the total cost, distributed on the acre basis, as well as per thousand linear feet, per ton, and per carload of tile; and also the hours consumed by this element, distributed on the same basis.

Tile

Tile is usually sold per 1000 linear feet, and, in large orders, in carload lots; while contractors and tile manufacturers base their market price on the cost of handling a ton of materials. Table XI, page 55,

gives the total cost of tile on each project, distributed on the usual acre basis; and in connection with Tables VIII, IX, and X, per 1000 linear feet, per ton, and per carload.

Table VII, page 51, shows the actual linear feet of tile of the different sizes used on each project in each class of land. However, it is also convenient to consider the tile, from the general standpoint of size, under two classifications: (1) that required for mains and submains, which includes all tile more than 6 inches in diameter; (2) that required for minor field laterals, and including all tile 6 inches in diameter and less. Table VIII, page 52, shows the linear feet of tile on each project, distributed under the two main classes and also on the established acre basis. On flat and peat lands the general parallel spacing of minor laterals approximates 100 feet, whereas on rolling lands the systems are natural systems and the position and extent of minor laterals are governed almost wholly by the general topography.

Table IX, page 53, gives the tons of tile used on each project according to size, and distributed on the established acre basis; while Table X, page 54, gives the same information expressed in minimum carloads of 30,000 pounds. The data of Tables VIII and IX can be used in making preliminary estimates of tile required for a given class of land.

Freight on Tile

Railroad tariffs on tile, as on other commodities, are very unstable through a period of years. Therefore dollars-and-cents statements of freight are of little value in a discussion of this character except as they are used in connection with the general trend of costs *according to the length of railroad hauls.* For purposes of approximate estimating, therefore, the average length of railroad haul is of service. Approximate details of this haul for each project are given in Table XII, page 56. The actual miles were taken from printed railroad schedules, where the routing was known. In the few cases in which it was not known and in which more than one routing was possible, the most probable and usually the shortest routing was taken. The total carloads in this table are taken from Table IX. The total money cost of freight, as well as its distribution for each project, is shown in Table XIII, page 57. The most interesting and most useful unit is the cost per carload mile of railroad haul. The cost per hundredweight in carload lots, which is the customary commercial unit in which freight is figured, as well as the trend of such rates, may easily be obtained in any case from the cost per ton of tile.

Haul and Distribution

Unloading tile from the cars, hauling it from the railroad station, and distributing it along the drain lines is usually done by the farmer,

using man labor for loading and unloading and either horse or gasoline power for hauling. Conditions vary widely in different localities and at different times of the year. It has, therefore, been pretty well established by custom that in estimating haul and distribution we should follow the lead of the railroads in establishing a fundamental unit of cost which would fit our case; that is, this unit should be the cost of hauling one ton one mile, or what is commonly known as the cost per ton mile. Table XII, page 56, shows, along with the carloads and carload miles, the average miles of team or truck haul on each project, and the total tons hauled, together with the product of these two sets of items which gives the total ton miles under each project. Table XIV, page 58, shows the actual money cost and the labor cost in man hours, of haul and distribution of the tile.

Trenching, Laying, and Blinding

Table XV, page 60, gives the actual money cost and the cost in man hours of labor for trenching, laying, and blinding. The figures are of value in approximate preliminary estimating and for approximate comparison with other elements, but should not be used for close estimating or as a basis for bids because this element is one of the largest two elements in the cost of tile drainage and the amount of labor involved in digging trenches varies widely with the size of the tile, the depth of the trench, and the character of the soil and subsoil, and this variation is not uniform. In this connection it is therefore necessary to consider the average cut on any given project for the different sizes of tile, and also the character of the digging as determined by the kind of soil or its local physical condition; while the surface character of the land has no appreciable influence in fixing the unit rate of cost in this element. The importance and intricacy of this element are such as to warrant separate treatment.

BALANCED COST SCHEDULE FOR TILE TRENCHING[1]

General Considerations

Character of Digging

The character of digging falls naturally into three classes; easy, average, and hard. A schedule is developed covering each of these classes. Of the 18 projects only 2 fall within the first class, both of these being in peat; 14 projects fall within the second class, almost wholly in mineral soil; and 2 fall within the third class, also in mineral soil.

Easy digging.—Under easy digging are included soils and soil conditions which presented no serious obstacles to spading and casting—light soils of rather loose texture, free from roots, stumps, loose

[1] This schedule is built on a man-hour labor unit.

gravel, stones, or boulders—in which the spade settled readily under light pressure and where there was just enough moisture to give firmness to the soil, to make the trench walls self-sustaining and the spade slice coherent enough to cast easily. Under this class might be listed such soils as peat free from tough fibers, roots, and stumps; light, porous sandy loams; sandy clays; and the finer damp sands. For projects under this class, see Table XVI, page 61.

Average digging.—Under average digging are included soils or soil conditions requiring considerable but not excessive pressure to settle the spade, and considerable effort to cast; soils with a slightly frozen surface—possibly requiring the occasional use of the pick—a few cobblestones, boulders, or stumps; or material which, while easily spaded, is hard to cast because of its weight but is generally sufficiently coherent to make casting easy and caving of trench walls infrequent. Such conditions occur most frequently in ordinary prairie soils except after protracted drouth and when the ground is frozen. For projects under this class, see Table XVII, page 62.

Hard digging.—Under hard digging are included all conditions not included in the other classes—conditions of moisture or soil texture that cause a fairly constant tendency for the trench walls to cave; looseness, heaviness, or wetness of material that makes it difficult to cast; a degree of hardness, either natural or on account of drouth, that makes spading difficult or impossible and necessitates the frequent use of the pick or explosives; the presence of heavy sand and gravel, frequent cobblestones, boulders, or stumps. Under this class may be listed ground frozen to a considerable depth, hard pan, cemented gravel, coarse loose sand, heavy gravel, very stony soils, and soils so hard from lack of moisture as to be difficult or impossible to spade in ordinary fashion. For projects under this class, see Table XVIII, page 64.

Limiting Sizes of Tile and Depths of Trench

The tile used ranged from 4-inch to 22-inch and depths of cut varied from 3 feet to slightly under 12 feet. Data on sizes of tile and depths of trench were complete on all projects.

Altho 4-, 5-, and 6-inch tile are seldom used in trenches more than 6 feet deep and more seldom in those more than 8 feet deep, and altho trenches of less than 4 feet for tile from 18-inch up are undesirable, for the sake of completeness and uniformity of appearance, Tables XX, XXI, XXII, XXIII and the corresponding curves shown in Figures 20, 21, 22, and 23 are constructed to cover trenches from 3 feet to 12 feet deep for tile from 4 inches to 24 inches in diameter.

Time Factor

Of the two projects in easy digging, one falls under class 1 and one under class 2 as to reliability of time data, the latter constituting about 81 per cent of the total work in easy digging.

Of the two projects in hard digging, one falls under class 1 and the other under class 2 as to reliability of time data, the latter constituting only about 38½ per cent of the total hard digging.

Of the remaining 14 projects, all average digging, eight fall under class 1, four under class 2, and two under class 3, as to reliability of time data, the latter two classes combined constituting about 63½ per cent of the total average digging.

Reasonable Maximum Error in Estimated Time and Resultant Work Units

The approximations under class 2 probably do not involve a maximum error in total time on any project to exceed 10 per cent, and those under class 3 not to exceed 15 per cent. Hence the error in work units per hour under each class of digging will not exceed: easy digging, 8 per cent; average digging, 8 per cent; hard digging, 4 per cent.

It is therefore also probable that the error in time per 100 feet of trench obtained from the tables and diagrams in this report will not greatly exceed: easy digging, 9 per cent; average digging, 9 per cent; hard digging. 4 per cent.

Character of Tables XVI, XVII, and XVII

Tables XVI, XVII, and XVIII, pages 61, 62, and 64, present physical facts of general interest on the different projects involved, as well as some data derived in the process of computing the final schedules, and explained later.

METHOD OF PROCEDURE

Fixing Upon a Work Unit

In order to secure a schedule based on the fundamental scientific idea of work as expressed in foot-pounds, it was first necessary to determine a work unit readily adaptable to the class of work involved. As density of material on different jobs varies widely, it is evident that the foot-pound is not a suitable work unit. But if it is assumed that the material excavated *on any given job,* taken as a whole, would be more or less uniform in texture and density, a volumetric unit proportional to the foot-pound would be a suitable *comparative* work unit. Hence, the work unit here adopted is *the lifting of one cubic foot of earth through a vertical distance of one foot,* as this is readily determined from the data on hand. The number of such units performed in digging a trench of any given depth for any given size of tile and the number of such units constituting a normal hour of work were computed

as shown in the discussion of Tables XIX and XX, pages 64 and 65. By reference to Figure 19b, page 28, it will be seen that the determination of the foregoing values involves the computation of the areas of cross-section of trench and spoil bank, and of the vertical distance between the centers of gravity of these cross-sections.

It has been stated that most hand tilers think of a trench in depths of the number of spades rather than the number of feet, everything up to 3 feet being called two-spade work, from 3 to 4½ feet, three-spade work, and so on, and that a cost based on cubage does not take this feature into consideration. This fact is immaterial, because the cost data for depths of 3 feet, 4½ feet, 6 feet, etc., representing depths of 2, 3, and 4 spadings, etc., may be taken from the tables or curves instead of consecutive feet. The values thus obtained are still correct and usable because based on the established unit of work, that is, the lifting of one cubic foot of earth through a vertical distance of one foot.

GENERAL ASSUMPTIONS

(See Fig. 19a, Fig. 19b, and Table XIX)

1. **Uniform type of trench cross-section.**—For small sizes of tile many skillful tilers prefer to save work by digging to a form of cross-section approximating that shown in Figure 19a, leaving a shoulder at the top of the last spading in order to provide a working shelf to stand on, and width enough to work in; for which the minimum is about 16 inches. However, this shoulder practically disappears with tile 10 inches and upward in diameter and it was found that the use of such a shoulder caused an awkward non-uniformity in the law of the trenching curve for small sizes of tile as compared with that for the larger sizes. On this account, in the final development of the work unit, the shoulder was omitted and the sides of the trench were reckoned as a continuous surface upward from the springing line of the concave that forms the bottom of the trench, the type of section used throughout being illustrated in Figure 19b.

2. **Batter or side slope of trench walls.**—Experience has shown that when a narrow trench is being dug, even when the sides of the trench are to be as nearly vertical as possible, the natural tendency is to give a slight slope or batter to the sides where the soil is firm enough to stand without sheathing. Furthermore, giving a slight batter to the face of an excavation seems to increase its self-sustaining power in undisturbed soils that are tolerably firm. Some study of this problem was made at this station several years ago, and the records of the work indicate that tendency and practice give an average batter of about 0.75 inch to the foot of depth, or practically 0.06 of a foot to a foot of depth. Hence a uniform batter of this ratio was used on each wall,

making a uniform total flare of 0.12 foot per foot of depth, reckoning upward from the springing line in each case.

3. **Location of springing line.**—For simplicity in computation, the springing line was assumed at the extremities of the horizontal diameter of the basal concave. The theoretical error introduced by this assumption involves nothing of greater significance than the third place of decimals in the area of trench cross-section, expressed in square feet.

4. **Outside diameters of standard tile.**—All standard tile was assumed to have an outside diameter equal in tenths of a foot to the number of inches representing its internal diameter; that is, the outside diameter of a 4-inch tile is considered as 0.4 of a foot, that of an 8-inch tile as 0.8 of a foot, that of a 12-inch tile as 1.2 feet and so on. This is nearly exact and is systematic.

5. **Overwidth of base of trench.**—The additional width of trench allowed at the springing line to admit handling the tile readily and to allow for irregularities in individual tile, was taken uniformly at 15 per cent of the outer diameter.

6. **Spoil bank; top width, and slopes.**—The spoil bank was considered to be on level ground and to have an average top width of one foot, and side slopes of 1½ feet horizontal run to 1 foot of vertical rise.

7. **Average lift.**—The average lift was considered as the vertical distance between the center of gravity of the trench cross-section and that of the spoil bank cross-section. See "Method of computation of Tables XIX and XX.")

8. **Lowering and placing the tile, a work element.**—Lowering the tile into the trench was considered work of the same general type as excavating the earth, and the vertical height through which the tile was moved was in all cases considered equal to the depth of the trench.

9. **Adjustment of machine and team hours to man hours.**—In computing the total hours of trenching labor on each project wherever the Bennett horse traction ditcher was used (Item 9, average digging, Table XVII), it was found to be the equivalent of about 4.4 average men. Wherever the Buckeye traction ditcher was used (Items 11 and 12, average digging, Table XVII), careful comparisons of time and amount of work with the other projects in the same class of digging indicated that it was the equivalent of about 8.4 average men on those jobs. These two equivalents were used in reducing all the machine trenching labor to a man-hour basis. Where team labor entered into the trenching work, a team without driver was in all cases balanced against a man tiler.

It has been the observation of some that trenching machines of the heavy traction-wheel type are more efficient in deep trenching than in shallow trenching. Strictly speaking, therefore, it is probably incorrect to assume that trenching machine efficiency is constant regardless of depth of trench. However, for the following reasons, it is not probable that this assumption will seriously affect the practical value of the schedule herein developed.

Only a small part of the machine work included in the data used involved trenches more than 6 feet deep and most of the remainder involved trenches under 4 feet, none of which is to be considered as deep trenching.

It has been the general observation of the writer (not, however, backed by specific data) that hand labor, also, is more efficient on trenches from 4 to 6 feet in depth and for sizes of tile from 12-inch upward than on shallower work with smaller tile.

On the general run of farm drainage projects only a comparatively small part of the trenching exceeds 6 feet in depth.

In the construction of any farm drainage project, therefore, it is probable that the variation of labor efficiency relative to depth of trench is fairly consistent throughout, regardless of the method by which the work is done, and that this variation is not sufficient seriously to affect the usefulness of the schedule herein developed.

METHOD OF COMPUTATION OF TABLES XIX AND XX

Ratio of tile material to excavated material.—The ratio, "s" between the density of the material in tile walls and that of average soil excavated from tile trenches, was obtained by computing the average of a series of air-dry weights of standard drain tile, both concrete and clay or shale, and comparing these with the generally accepted average weight of clay or heavy clay loam soils. These ratios are about as follows:

For clay or shale, about.....	1.0
For concrete, about	1.25

It was assumed that by far the greater part of the tile 8 inches and less in diameter would be clay or shale tile, while above 8 inches it might stand an equal chance of being either clay, shale, or concrete, so for 8-inch tile or less "s" was taken as 1.0 and for all other sizes as 1.125 or 1-1⅛.

Areas and distances.—The area of cross-section of the standard tile sizes, the area of the trench cross-section and of the spoil bank cross-section, as well as the location, in vertical axes, of their centers of gravity and the vertical lift between them were all computed by standard geometrical and algebraic methods.

Table XIX, page 64, is presented as illustrative of ten such tables that it was necessary to compute, one for each size of tile as follows: for 4-, 5-, and 6-inch; 8-inch; 10-inch; 12-inch; 16-inch; 18-inch; 20-inch; 22-inch; and 24-inch. The meaning of the various values shown in Table XIX and the methods by which they were computed are shown in the following lists of symbols and formulas.

It was inadvisable to compute such tables for 7-, 9-, and 15-inch tile, the curves in Figures 20, 21, 22, and 23 being so close together as to be confusing.

Explanation of symbols shown on Figures 19a and 19b and used in Table XIX

(All dimensions are in linear feet and all areas in square feet.)

On figures 19a and 19b and Table XIX

D = total depth of trench
T = width of trench at top
d = diameter of semi-circular concave forming base of trench
Y = vertical depth of trench from top
to base of battered slopes, Figure 19a;
to springing line, Figure 19b
Y_1 = vertical depth of trench from
base of battered slopes to bottom of trench, Figure 19a;
springing line to bottom of trench (d/2, or radius of semicircular concave), Figure 19b
O′ marks the center of gravity of trench cross-section
G = vertical distance, surface of ground to center of gravity of trench cross-section
1 ft. = assumed constant width of top of spoil bank
y = vertical height of spoil bank
O marks the center of gravity of spoil bank cross-section
g = vertical distance from base of spoil bank to center of gravity of spoil bank cross-section

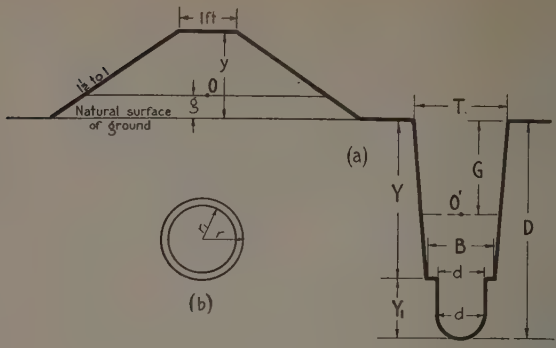
On Figure 19a only

B = width of trench at base of battered side slopes

In Table XIX only

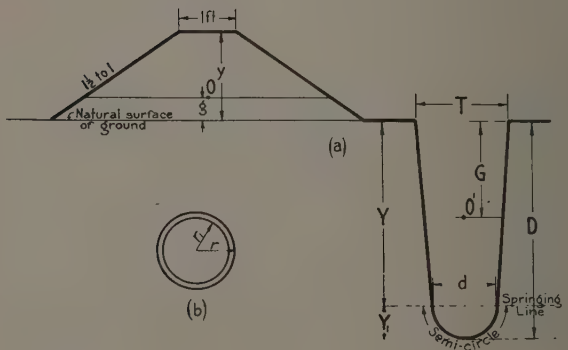
A = area of cross-section of trench or of spoil bank
a = area of cross-section of tile wall
r = outer radius of tile
r_1 = inner radius of tile
π = ratio of circumference of a circle to its diameter (= 3.1416 approx.)
s = ratio of density of material in tile wall to density of ordinary excavated material

$0.12 = \frac{T-d}{Y}$, assumed constant rate of spread of trench cross-section from springing line to top



(a) TYPICAL CROSS SECTION OF SPOIL BANK AND TILE TRENCH FOR TILE LESS THAN 10 INCHES IN DIAMETER.
(b) TYPICAL CROSS SECTION OF TILE WALL.

Fig. 19a. Typical Cross-Section of Spoil Bank and Tile Trench for Tile Less Than 10 Inches in Diameter



(a) TYPICAL CROSS SECTION OF SPOIL BANK AND TILE TRENCH FOR TILE 10 INCHES IN DIAMETER AND LARGER.
(b) TYPICAL CROSS SECTION OF TILE WALL.

Fig. 19b. Typical Cross-Section of Spoil Bank and Tile Trench for Tile 10 Inches in Diameter and Larger

Statement of formulas used in computing Table XIX from Figure 19b

$$d = 115\% \text{ of outer diameter of tile} = 1.15 \times 2r \quad (1)$$

$$Y = D - d/2 = D - Y_1 \quad (2)$$

$$T = d + 0.12\,Y \quad (3)$$

$$A = \frac{\pi d^2}{8} + \frac{(d+T)\,Y}{2} = \tfrac{1}{2}\left[\pi Y_1^2 + (d+T)\,Y\right] \quad (4)$$

$$= (2T - 0.12\,G)\,G = 2TG - 0.12\,G^2 \quad (5)$$

$$= \frac{(2+3y)\,y}{2} = y + \frac{3y^2}{2} \quad (6)$$

$$= \left[2\,(1+3y) - 3g\right] g = 2\,(1+3y)\,g - 3g^2 \quad (7)$$

$$\text{From (5), } G = \frac{T - \sqrt{T^2 - 0.12\,A}}{0.12} \quad (8)$$

$$\text{From (6), } y = \frac{-1 + \sqrt{1+6A}}{3} \quad (9)$$

$$\text{From (7), } g = \frac{1+3y - \sqrt{(1+3y)^2 - 3A}}{3} \quad (10)$$

$$a = \pi\,(r^2 - r_1^2) = \pi\,(r - r_1)\,(r + r_1) \quad (11)$$

asD = work units per linear foot of trench due to lowering tile into trench (12)

$A(g+G)$ = work units per linear foot of trench due to excavating trench (13)

$A(g+G) + asD$ = total work units per linear foot of trench (14)

Table XVIII gives the values of the quantity $A(g+G) + asD$ for all sizes of tile from 4-inch to 24-inch and for all depths of trench from 3 to 12 feet. This table is a compilation of the data in the last column on the right in all the ten tables mentioned, like Table XIX, and of which Table XIX is one.

Figure 20, page 65, is plotted from the data of Table XX. The values given in Table XX are used in the computation of the final schedules, Tables XXI, XXII, and XXIII, as later shown under discussion of "Method of computation of final schedules."

Computation of total work units.—The items in Tables XVI, XVII, and XVIII, in the columns headed "Work units per linear foot," were read from Figure 20 according to the average cut recorded in Table XIX for each size of tile. The product of each of these values from Figure 20 by the corresponding linear feet of tile of the given size gives the total number of standard work units for that item of the job. All such products are shown in the column in Tables XVI, XVII, and XVIII, headed "Work units, total per item."

METHOD OF COMPUTATION OF FINAL SCHEDULES
(Tables XXI, XXII, and XXIII)

Hour-labor coefficients (Work units per man hour).—Dividing the grand total standard work units in any class of trenching, as given in Tables XVI, XVII, and XVIII, by the grand total hours of trenching labor, as given in the same tables, gave the number of work units constituting an average hour of man labor in that type of digging. As shown under the several types in Tables XVI, XVII, and XVIII, these are as follows:

For easy digging	70
For average digging	60
For hard digging	43

Multiplying the successive items of work units per linear foot of trench (Table XX) by 100 and dividing these products through in succession by the foregoing hour labor coefficients for the given class of digging, gave the items in Tables XXI, XXII, and XXIII, pages 66, 67, and 68, respectively, for each size of tile and depth of trench. Figures 21, 22, and 23 were plotted from the data of Tables XXI, XXII, and XXIII, respectively.

RELIABILITY OF TRENCHING SCHEDULES

These trenching schedules are independent of economic conditions and entirely dependent on the efficiency of labor. The data on which the schedules for easy and for hard digging are based are meager, but as they comprise all the exact data now available in these two classes of digging, the resulting schedules are the best to be had. If a greater mass of exact data becomes available in the future, it will simply serve to support or improve these schedules in proportion to the amount and exactness of the additional data presented. The schedule for average digging is backed by a mass of data which gives it decided stability and reliability as a basis for estimates and bids. The greater mass of digging is probably average, and schedules from this table should fit closely. If money values of trenching are wanted, they are also readily computed from the time schedules wherever the value of an hour of labor is known. For example, if at the given time, common tiling labor is worth 40 cents per hour and it is desired to know the right price for 100 feet of 6.5-foot trench for 10-inch tile, for average digging, Figure 22 shows the hours required to be 58. This, multiplied by 40 cents, gives the correct price, or $23.20.

If it is desired to include cost of board or contractor's profit, the bare *price of labor per hour* should be increased the proper percentage in each case.

It is evident that such a schedule can not be used to cover cases in which unusual difficulties occur or where plank stays or curbing must be placed, but even with these limitations this schedule will tend to lead to more balanced engineers' estimates and contractors' bids.

Some prefer tables to curves and Tables XXI, XXII, and XXIII can be used instead of the curves in Figures 21, 22, and 23.

PRACTICAL ILLUSTRATION OF USE OF TRENCHING SCHEDULES

The following is an estimate of the time required to do the trenching, laying, and blinding of the tile on a small drainage system installed by hand on the Experimental Farm at Duluth, Minnesota, in the fall of 1924.

Explanation of conditions.—Most of this digging was in the hard, stony, clay soil of the Lake Superior region, some was in peat, and some was in mineral soil. The part of the main constructed of 8- and 12-inch tile was laid in the slope of an existing open ditch, later partly filled, whose bottom was only slightly over a foot above the grade of the tile. Hence the average cut was materially reduced from that indicated by the levels on the hubs which were on the high side of the

tile line, and most of the excavated material did not have to be lifted the full height of the trench into a high spoil bank but could simply be rolled over the side into the bottom of the ditch. A careful examination of these conditions and computations based on the existing physical facts showed the reduction from the normal lift to be about 25 per cent. Hence, for the 8- and 12-inch tile, the normal time of trenching to the average depth from tops of hubs was taken from the curves and reduced 25 per cent before extending.

Details of estimate

Total hrs.

Small open ditch below tile outlet, hard digging, 2098 cubic feet of excavation, 1.8 feet average lift; hence total time equals 2098 times 1.8 or a total of 3776 work units divided by 43 per hour of man labor..... 86

Open intercepting ditches at head of system, easy digging, 4722 cubic feet of excavation, 1.1 feet average lift; hence total time equals 4722 times 1.1, or a total of 5194 work units divided by 70 per hour of man labor..... 74

Tile

Lin. ft.	Size	Av. cuts from hubs	Class of digging	Time per 100 ft. (from curves)	Adjustment	Adjusted hours Rate	Adjusted hours Total
	inches	feet		hours	per cent		
600	12	3.00	hard	20	—25	15	90
200	10	under 3.00	hard	16		16	32
1000	8	under 3.00	hard	13	—25	10	100
450	6	4.44	easy	13		..	59
565	5 & 6	3.00	hard	10		..	57
250	5	under 3.00	easy	6		..	15
250	5	3.21	easy	7		..	17
400	5	3.44	easy	7		..	28
310	5	3.76	easy	9		..	28

Total hours for job..... 586
Total hours of man labor actually required..... 580

Error of estimate..... + 6
Slightly over 1 per cent.

REFILLING TRENCHES

The refilling of the trenches may be done by various methods, the method adopted in any given case being mostly dependent on the size of the job to be done altho to some extent influenced by the character of the field surface and the governing lengths of the field laterals. It is convenient to figure the labor cost of filling trenches at so much per 100 linear feet according to size of tile and depth of trench, as the amount of labor required will vary almost exactly with the amount of material to be moved; but it is only slightly affected by the distance this material must be moved, as the only labor involved is in pushing the

spoil bank over to the trench, a comparatively short distance horizontally, gravity doing the rest of the moving. The work is usually done by the cheapest class of help. If the refilling is done with teams or machinery or both, it is difficult to reduce all the time spent to a man-hour basis. A close study of the data on these projects seemed to indicate that an arbitrary time unit of 1 team hour plus 1⅓ man hours is the most convenient and satisfactory for use on this cost element; hence that unit was established, with distribution of cost in both money and time extended in Table XXIV, page 70, in the same manner as with the elements previously discussed.

The labor of refilling trenches will vary considerably according to size of tile and depth of trench, as was the case with trenching, laying, and blinding, altho to a less extent and less intricately. The variation is a direct variation in terms of the cubic feet or cubic yards of material to be moved per unit length of trench. Therefore, it has seemed best in this case, also, to establish a time-cost schedule somewhat similar to that finally evolved for trenching, laying, and blinding. However, as the material does not have to be dug or lifted but simply pushed sidewise from a more or less loose spoil bank, the element of character of digging need not be considered, but it is necessary to determine the average number of cubic feet of earth moved per hour. The total volume of all trenches on all projects divided by the total number of hours required in refilling the trenches will give this average. Table XXV, page 72, gives the average cut, area of cross-section, and total volume of trench on each project for each size of tile and the total volume of all trenches on all projects. The resulting average number of cubic feet moved per hour unit is 489.4. This is so near to 490 that assuming it to be 490 will give a factor more convenient to handle without introducing an appreciable error.

If this factor (490) be successively divided into the areas of trench cross-section for the different sizes of tile and depths of trench shown in column "A," in Table XIX and the similar tables, and the resulting quotients each multiplied by 100, the successive results will be the average number of hour units required to fill 100 linear feet of trench for each given size of tile and depth of trench. Table XXVI, page 75, gives this information for sizes of tile from 4- to 24-inch and for depths of trench from 3 to 12 feet; and Figure 24 shows the same data in curves similar to those developed for trenching, laying, and blinding.

OUTLET PROTECTION AND MISCELLANEOUS

Protection of outlet and miscellaneous expense may involve only extra material or both extra material and extra labor. The expense involved depends very largely on local conditions and consequently varies from little or nothing to a very appreciable figure, so the data on this element from any set of projects do not furnish conclusive information. The available data are given here, however, to make the whole fund of information as complete as possible. The cost of these elements in both money and time, distributed on the usual basis, is given in Tables XXVII and XXVIII, pages 76 and 78.

Altho actual costs do not directly involve the items of average cut, average gradient, and average size of tile, the information contained herein will not be complete or of its fullest value without the inclusion of data furnishing these three items, because depth of cut, gradient, and size of tile are essential elements of tile drainage design which are intimately bound up with the subject of cost. Therefore tables are included giving these data. The average cuts, classified according to size of tile and character of land surface, are shown in Table XXIX, page 80; and the average sizes of tile and average grades, classified according to character of land surface, are shown in Table XXX, page 87. Table XXXI, page 82, giving the approximate weight per linear foot of tile from 4-inch to 24-inch, inclusive, is also added because both are necessary and convenient to a full consideration of these cost data.

PRACTICAL ILLUSTRATIONS OF THE USE OF THE TABLES OF COST DATA

The following examples illustrate a few of many ways in which the cost data in this bulletin may be used to obtain preliminary estimates of approximate accuracy, according to the amount of detail used in working them out.

Assumed Details

Flat land
Average digging conditions
Area of watershed on farm..... 240 acres
Area of land drained..... 125 acres
Area of land reclaimed..... 70 acres

Illustration of a Fairly Exact Method Such as an Engineer Would Be Likely to Use

This case seems somewhat similar to project 11; therefore, using project 11 as a guide:

Table XXX gives average size of main tile on this project as 12 inches.

Table XXIX gives average cut on main tile as 5.37 feet.

Table XXIX gives average cut for the small laterals as 3.53 feet.

Table XXXI gives average weight per foot of 12-inch tile as 43 pounds, of 5-inch tile as 10 pounds.

Amount of Tile Required—from Table VIII, Project 11

6 inches and under	over 6 inches
240 acres at 144 = 34,560 lin. ft.	240 acres at 40 = 9,600 lin. ft.
or 125 acres at 276 = 34,500 lin. ft.	or 125 acres at 78 = 9,750 lin. ft.
or 70 acres at 576 = 39,690 lin. ft.	or 70 acres at 160 = 11,200 lin. ft.

These figures seem to indicate that the amount of reclaimed land is a poor index, probably on account of its great variation. Hence rejecting item 3 in both cases and taking the average of the other two gives:

34,530 lin. ft. of 5 in. at 10 lbs. per ft. = 345,300 lbs. or 172.66 tons
9,675 lin. ft. of 12 in. at 43 lbs. per ft. = 416,025 lbs. or 208.00 tons

Total 44,205 lin. ft. 761,325 lbs. or 380.66 tons or 25.38 carloads

Engineering and Supervision

44,205 lin. ft. of tile at 11.22 hrs. per M. ft. (Table VI) at $1.01 per hr. (Table VI) $500.94

Tile

44,205 lin. ft. at $56.59 per M. ft. (Table XI) 2501.56

Freight

25.38 carloads at $10.69 per carload (Table XIII) 271.31

Haul and Distribution

380.66 tons at 1.87 hr. units per ton (Table XIV) at $0.35 per hr. unit (Table XIV) 249.14

Trenching, Laying, and Blinding

34,530 lin. ft. at 10.5 hrs. per 100 ft. (Table XXII for 5 in. tile av. cut 3.53) at $0.28 per hr. (Table XV) $1015.18
9,675 lin. ft. at 47.0 hrs. per 100 ft. (Table XXII for 12 in. tile av. cut 5.37) at $0.28 per hr. (Table XV) 1273.23

Total trenching, laying, and blinding 2288.41

Refilling Trenches

34,530 lin. ft. of 5 in. av. cut 3.53 at 0.6 hr. unit per 100 ft. (Table XXVI) at $0.81 per hr. unit. (Table XXIV) $167.82
9,675 lin. ft. of 12 in. av. cut 5.37 at 1.7 hr. units per 100 ft. (Table XXVI) at $0.81 per hr. unit. (Table XXIV) 133.22

Total refill 301.04

Outlet Protection

44,205 lin. ft. at $1.13 per M. ft. (Table XXVII)..... 49.95

Miscellaneous

None

Grand total cost..... $6162.35

If the same example be worked out by using the average units and rates for all flat land projects from the same tables, the factors and results will be as follows:

Lateral tile 5-inch., average cut 3:14 feet; main tile 14-inch, average cut 5.24 feet.

Weight of 14-inch concrete tile, 59 pounds per linear foot (Table XXXI).

Amount of tile required (rejecting the reclaimed land factor as before)

6 inches or less		over 6 inches	
240 acres at 180 =	43,200 lin. ft.	240 acres at 32 =	7,680 lin. ft.
125 acres at 264 =	33,000 lin. ft.	125 acres at 47 =	5,875 lin. ft.
Average	38,100 lin. ft.	Average	6,778 lin. ft.
38,100 lin. ft. at 10 lbs. =	381,000 lbs. or 190.50 tons		
6,778 lin. ft. at 59 lbs. =	399,902 lbs. or 199.95 tons		
Totals 44,878 lin. ft.	780,902 lbs. or 390.45 tons	or 26.03 carloads	

Engineering and Supervision

44.878 × 10.17 × $0.86..... $ 392.51

Tile

44.878 × $50.58..... 2269.93

Freight

26.03 × $24.05..... 626.02

Haul and Distribution

44.878 × 24.20 × $0.35..... 380.11

Trenching, Laying, and Blinding

381.00 × 8.0 × $0.29..... $883.92
67.78 × 52.5 × $0.29..... 1031.95

Total 1915.87

Refilling Trenches

381.00 × 0.5 × $0.80..... $152.40
67.78 × 2.0 × $0.80..... 108.45

Total 260.85

Outlet Protection

44.878 × 1.10 × $0.90..... 44.43

Miscellaneous

None

Grand total cost..... $5889.72

This total, in comparison with the first computation with its more careful selection, is in error, but only about 4 per cent, which is close for an estimate.

The average money rates per hour herein used are the averages from the tables and are used only to illustrate the method. In actual cases these money rates per hour should be replaced by what are known, at the time, to be the prevailing local rates.

Illustration of an Approximate Short Method Such as a Farmer Might Use

To obtain approximate total cost, again following project 11.

240 acres of watershed at $24.95 total cost per acre from Table III....	$5988.00
125 acres drained at $47.97 total cost per acre from Table III....	5996.25
Average	$5992.13

Cost of tile, on same basis, from Table XI becomes

240 × $10.42.....	$2500.80
or 125 × 20.04.....	2505.00
Average	$2502.90

From Table IV referring to project 11, cost of tile represents 41.8 per cent of the total cost.

Hence total cost should be $\frac{2502.90}{0.418}$ or $5987.80.

Any of these four results is reasonably close to the standard established in the first example, the error in no case much exceeding 4½ per cent.

Illustration of a Handy Method for the Contractor

Similarly, a contractor interested largely in the trenching labor might thus figure from the units for trenching, laying, and blinding, taking his units for flat land from Table XV.

240 acres at $9.35 per acre.....	$2244.00
125 acres at 17.99 per acre.....	2248.75
Average	$2246.38

Table IV shows the item of trenching, laying, and blinding for project 11 to be 37.5 per cent of the total. Hence the total should be $\frac{2246.38}{0.375}$ or $5990.34, which is reasonably close.

Illustration of a Handy Method for the Tile Manufacturer

A tile manufacturer would probably base his estimates on the weight of tile required, in tons, taking his units from Tables IX and XI thus:

240 × 1.50 tons × $6.94 per ton.....	$2498.40
125 × 2.89 tons × 6.94 per ton.....	2507.07
Average	$2502.74

The cost of tile as shown above from Table IV is 41.8 per cent of the total cost, hence the total cost should be $\frac{2502.74}{0.418}$ or $5987.41.

The general assumption from any of the foregoing is that the total cost would be about $6000, which is probably about right for average conditions.

SPECIAL CONDITIONS NOT COVERED

It should be borne in mind that schedules and unit costs here presented apply only to the actual work and materials on individual farm drainage and do not include contractor's profit, employees' liability insurance, or other special features caused by local, natural, or business conditions. If these must be considered, suitable allowance must be made for them.

ACKNOWLEDGMENTS

Acknowledgments are due to John T. Stewart who, while agricultural engineer of this experiment station, collected a mass of valuable cost data which forms a very considerable portion of the material in this bulletin; to H. B. Walker, agricultural engineer of the Kansas State Agricultural Experiment Station, and E. R. Jones, agricultural engineer of the Wisconsin State Agricultural Experiment Station, for their constructive criticism and suggestions, particularly with reference to the development of the cost schedules for trenching, laying, and blinding; to George F. Krogh, of this division, for the drawings presented; and to farmers throughout the state whose hearty co-operation with the drainage staff made it possible to obtain a large part of the data presented in this bulletin.

TABLE I

LOCATION, DATE OF INSTALLATION, CLASSIFICATION OF LAND AFFECTED, AND DESCRIPTION OF SOIL AND CHARACTER OF DIGGING

Project No.	Location		Date of installation		Surface classification of land			Character of soil and subsoil
	Town	County	Month	Year	Rolling	Flat	Peat	
1	Zumbra Heights	Carver	Aug.-Nov.	1908	X			Clayey moraines, some common marsh, peat pockets, some hardpan. Average digging
2	Opposite Halstad, Minn.	Trail, No. Dak.,	May-June	1909		X		Lake bed clay, extra tight, near gumbo, wet and sticky. Average digging
3	Belle Plaine, Scott Co.	Carver	Sept.-Oct.	1909	X			Same as project 1
4	St. Paul	Ramsey	Nov.-Dec. May	1909 1910		X		Sandy loam underlaid with thin layer of clay, then dry sand and gravel; gravel slightly cemented in spots. Average digging
5	Grand Rapids	Itasca	July-Sept.	1910		X		Overridden moraines; marsh and peat pockets, some deep peat, some very stony clay; heavy seepage. Digging varied
6	Oakland	Freeborn	Oct.-Nov.	1910		X		Black mucky loam over lake bed clay, some sticky gumbo. Average digging
7	Osakis	Douglas	May-June	1911	X			Boulder clay and stony ground moraines. Digging hard, largely pick work
8	Faribault	Rice	July-Nov. June-Aug.	1911 1912	X			Same as projects 1 and 3
9	Fargo, No. Dak.	Cass	June-Aug.	1915		X		Same as project 2
10	Duluth	St. Louis	Sept-Nov. May-June Oct.	1915 1916 1921	X			Very hard red clay mixed with fragments of trap rock. Digging very hard, much pick work

TABLE I—*Continued*

LOCATION, DATE OF INSTALLATION, CLASSIFICATION OF LAND AFFECTED, AND DESCRIPTION OF SOIL AND CHARACTER OF DIGGING

Project No.	Location		Date of installation		Surface classification of land*			Character of soil and subsoil
	Town	County	Month	Year	Rolling	Flat	Peat	
11	Moorhead	Clay	Sept.-Nov.	1916		X		Lake bed clay, very sticky after rains. Average digging
12	Glyndon	Clay	Nov. May-Nov.	1917 1918		X		Same as project 11
13	Coon Creek	Anoka	Aug.-Oct. April-May Nov.-Dec. May-June	1918 1919 1921 1922			X	Peat 4 to 6 feet deep underlaid by windblown sand to an indefinite depth. Digging mostly easy except where heavy seepage caused caving and running in of thin mud
14	Minneapolis	Hennepin	May	1919	X			Loose black loam over gravelly boulder clay, on a slope of a high moraine. Average digging
15	Newmarket	Scott	July-Sept.	1919	X			Same as project 1
16	Fens	St. Louis	May-June	1919			X	Deep peat filled with tamarack roots and stumps. Easy digging apart from roots and stumps
17	Paynesville	Stearns	June-Sept.	1921	X			Boulder clay under peat blanket 6 to 30 inches deep. Digging average, but sticky after rains
18	Meadowlands	St. Louis	Oct.-Nov.	1921		X		Sandy lake bed till with light peat layers in pockets, dry. Better than average digging
	Totals	14	Apr.-Nov.	1908-22	8	8	2	

* Classification of land on any project is indicated in the proper column by X.

TABLE II

AREAS, IN ACRES, ACCORDING TO DRAINAGE CHARACTER OF SURFACE

Farm project No.	All projects			Rolling land			Flat land			Peat land		
	Water-shed on farm	Drain-ed	Re-claim-ed	Water-shed on farm	Drain-ed	Re-claim-ed	Water-shed on farm	Drain-ed	Re-claim-ed	Water-shed on farm	Drain-ed	Re-claim-ed
1.....	73	15	10	73	15	10						
2.....	160	160	80	..	..	..	160	160	80			
3.....	76	14	14	76	14	14						
4.....	40	35	5	..	..	..	40	35	5			
5.....	185	120	100	..	..	..	185	120	100			
6.....	120	120	95	..	..	..	120	120	95			
7.....	120	20	8	120	20	8						
8.....	237	56	56	237	56	56						
9.....	95	95	32	..	..	..	95	95	32			
10.....	160	40	13	160	40	13						
11.....	300	156	76	..	..	..	300	156	76			
12.....	255	100	75	..	..	..	255	100	75			
13.....	40	28	28	..	..	..	..	..	..	40	28	28
14.....	3½	2	1	3½	2	1						
15.....	500	170	120	500	170	120						
16.....	20	15	15	..	..	..	..	..	..	20	15	15
17.....	139	35	35	139	35	35						
18.....	7	5	2½	..	..	..	7	5	2½			
Totals....	2530½	1186	765½	1308½	352	257	1162	791	465½	60	43	43

TABLE III

Total Costs and Costs per Acre per Project

Farm project No.	All projects				Rolling land				Flat land				Peat land			
	Total cost	Cost per acre			Total cost	Cost per acre			Total cost	Cost per acre			Total cost	Cost per acre		
		Of watershed on farm	Drained	Re-claimed		Of watershed on farm	Drained	Re-claimed		Of watershed on farm	Drained	Re-claimed		Of watershed on farm	Drained	Re-claimed
1.....	$ 615.00	$ 8.42	$ 41.00	$ 61.50	$ 615.00	$ 8.42	$ 41.00	$ 61.50								
2.....	4,672.08	29.20	29.20	58.40					$4,672.08	$29.20	$ 29.20	$ 58.40				
3.....	758.12	9.98	54.15	54.15	758.12	9.98	54.15	54.15								
4.....	427.24	10.68	12.21	85.48					427.24	10.68	12.21	85.48				
5.....	3,761.99	20.34	31.35	37.62					3,761.99	20.34	31.35	37.62				
6.....	1,544.77	12.87	12.87	16.26					1,544.77	12.87	12.87	16.26				
7.....	1,288.30	10.74	64.42	161.04	1,288.30	10.74	64.42	161.04								
8.....	3,529.27	14.89	63.02	63.02	3,529.27	14.89	63.02	63.02								
9.....	4,740.67	49.90	49.90	148.15					4,740.67	49.90	49.90	148.15				
10.....	2,791.52	17.45	69.79	214.73	2,791.52	17.45	69.79	214.73								
11.....	7,483.74	24.95	47.97	98.47					7,483.74	24.95	47.97	98.47				
12.....	10,168.93	39.88	101.69	135.59					10,168.93	39.88	101.69	135.59				
13.....	2,932.00	73.30	104.71	104.71									$2,932.00	$73.30	$104.71	$104.71
14.....	261.57	74.73	130.79	261.57	261.57	74.73	130.79	261.57								
15.....	9,065.27	18.13	53.33	75.54	9,065.27	18.13	53.33	75.54								
16.....	1,038.13	51.91	69.21	69.21									1,038.13	51.91	69.21	69.21
17.....	3,749.50	26.97	107.13	107.13	3,749.50	26.97	107.13	107.13								
18.....	277.92	39.70	55.58	111.16					277.92	39.70	55.58	111.16				
Totals..	$59,106.02				$22,058.55				$33,077.34				$3,970.13			
Averages		$23.36	$49.84	$77.21		$16.86	$62.67	$101.78		$28.47	$41.82	$71.06		$66.17	$92.33	$92.33

TABLE IV

COST OF EACH ELEMENT PER PROJECT AND PERCENTAGE THAT EACH ELEMENT REPRESENTS OF THE TOTAL COST

Farm project No.	Total cost	Engineering and supervision		Tile		Freight		Haul and distribution	
		Cost	Per cent	Cost	Per cent	Cost	Per cent	Cost	Per cent
Rolling Land									
1.....	$ 615.00	$ 50.00	8.1	$ 171.65	27.9	$ 55.97	9.1	$ 24.48	4.0
3.....	758.12	104.35	13.8	166.97	22.0	37.02	4.9	68.28	9.0
7.....	1,288.30	163.17	12.6	407.03	31.6	150.39	11.7	66.88	5.2
8.....	3,529.27	215.75	6.1	1,198.45	34.0	277.51	7.9	198.00	5.6
10.....	2,791.52	342.76	12.3	278.10	10.0	301.79	10.8	133.10	4.8
14.....	261.57	56.05	21.4	54.12	20.7			30.00	11.5
15.....	9,065.27	947.20	10.4	2,589.36	28.6	369.48	4.1	500.30	5.5
17.....	3,749.50	214.07	5.7	1,278.11	34.1	294.29	7.9	330.64	8.8
Totals...	$22,058.55	$2,093.35		$ 6,143.79		$1,486.45		$1,351.68	
Av. per cents			9.5		27.8		6.8		6.1
Flat Land									
2.....	$ 4,672.08	$ 128.50	2.7	$ 1,833.19	39.2	$ 867.68	18.6	$ 371.87	8.0
4.....	427.24	39.00	9.1	86.91	20.3	20.79	4.9	10.13	2.4
5.....	3,761.99	234.82	6.3	1,589.13	42.2	572.69	15.2	180.52	4.8
6.....	1,544.77	157.20	10.2	406.17	26.3	46.03	3.0	182.00	11.7
9.....	4,740.67	216.08	4.6	1,211.25	25.5	587.16	12.4	118.25	2.5
11.....	7,483.74	625.00	8.4	3,126.58	41.8	320.65	4.3	292.72	3.9
12.....	10,168.93	722.25	7.1	4,138.24	40.7	386.74	3.8	899.22	8.8
18.....	277.92	42.32	15.2	68.38	24.6	72.62	26.1	10.20	3.7
Totals...	$33,077.34	$2,165.17		$12,459.85		$2,874.36		$2,064.91	
Av. per cents			6.6		37.7		8.7		6.2
Peat Land									
13.....	$ 2,932.00	$ 454.30	15.5	$ 498.41	17.0	$ 164.86	5.6	$ 122.40	4.2
16.....	1,038.13	212.84	20.5	136.78	13.2	43.16	4.2	18.00	1.7
Totals...	$ 3,970.13	$ 667.14		$ 635.19		$ 208.02		$ 140.40	
Av. per cents			16.8		16.0		5.2		3.5
Grand totals..	$59,106.02	$4,925.66		$19,238.83		$4,568.83		$3,556.99	
Grand av. per cents			8.3		32.5		7.7		6.0

TABLE IV—*Continued*

COST OF EACH ELEMENT PER PROJECT AND PERCENTAGE THAT EACH ELEMENT REPRESENTS OF THE TOTAL COST

Farm project No.	Trenching, laying, and blinding		Refilling trenches		Outlet protection		Miscellaneous	
	Cost	Per cent	Cost	Per cent	Cost	Per cent	Cost	Per cent
Rolling Land								
1	$ 256.00	41.6	$ 39.36	6.4		...	$ 17.54	2.9
3	316.50	41.7	65.00	8.6				
7	415.97	32.3	47.36	3.7		...	37 50	2.9
8	1,424.09	40.3	132.60	3.8	$21.50	0.6	61.37	1.7
10	1,515.76	54.3	207.61	7.4	12.40	0.4		
14	90.00	34.4	12.00	4.6	19.40	7.4		
15	4,296.63	47.4	289.80	3.2	72.50	0.8		
17	1,561.23	41.6	34.08	0.9	37.08	1.0		
Totals	$ 9,876.18		$ 827.81		$162.88	...	$116.41	...
Av. per cents		44.8		3.8		0.7		0.5
Flat Land								
2	$1,378.34	29.5	$ 67.50	1.5	$ 25.00	0.5		
4	221.35	51.8	36.00	8.4	13.06	3.1		
5	1,115.00	29.6	42.08	1.1	27.75	0.8		
6	670.37	43.4	57.00	3.7	26.00	1.7		
9	2,142.30	45.2	403.60	8.5	62.03	1.3		
11	2,806.29	37.5	250.00	3.3	62.50	0.8		
12	3,656.48	36.0	340.00	3.3	26.00	0.3		
18	80.50	29.0	3.90	1.4				
Totals	$12,070.63		$1,200.08		$242.34			
Av. per cents		36.5		3.6		0.7		
Peat Land								
13	$1,110.08	37.9	$ 196.04	6.7	$ 37.91	1.3	$348.00	11.8
16	376.00	36.2	50.00	4.8		...	201.35	19.4
Totals	$1,486.08		$ 246.04		$ 37.91	...	$549.35	
Av. per cents		37.4		6.2		1.0		13.9
Grand totals	$23,432.89		$2,273.93		$443.12	...	$665.76	
Grand av. per cents		39.7		3.9		0.8		1.1

TABLE V

TIME, IN HOURS, FOR LABOR ITEMS FOR EACH PROJECT AND FOR ALL PROJECTS

Farm project No.	Engineering and supervision	Haul and distribution of tile			Trenching, laying, and blinding			
	Man hours	Man hours	Team hours	Totals reduced to man hours	Man hours	Team hours	Machine hours	Totals reduced to man hours
Rolling Land								
1	40*	105	25	130	1,300			1,300
3	130	190	190	380	910			910
7	185	170	170	340	1,555			1,555
8	310	395	395	790†	4,010			4,010
10	175	340	330	670	3,072			3,072
14	75	30	30	60	100			100
15	1,560	770	770	1,540	5,420			5,420
17	130	570	530	1,100	2,350	10		2,360
Totals	2,605	2,570	2,440	5,010	18,717	10		18,727
Flat Land								
2	270†	780	520	1,300	8,120	150		8,270
4	80	25	20	45	540			540
5	300‡	390	390	780‡	3,100	230		3,330
6	230	520	520	1,040	1,990	40		2,030
9	130	100	100	200†	6,900	400	200§	8,180
11	620	440	400	840†	2,260	60	900‖	9,800
12	840	1,645	1,085	2,730	2,400	600	800‖	9,720
18	35	15	10	25	230			230
Totals	2,505	3,915	3,045	5,960	25,540	1,480	1,900	42,180
Peat Land								
13	450	210	210	420	1,288			1,288
16	160	20	20	40	488			488
Totals	610	230	230	460	1,776			1,776
Grand totals	5,720	6,715	5,715	11,430	46,033	1,490	1,900	62,683

* Partly estimated.

† Estimated.

‡ A small part estimated.

§ Horse-drawn machine—1 machine hour reckoned as equal to 4.4 man hours.

‖ Gas-power machine—1 machine hour reckoned as equal to 8.4 man hours.

TABLE V—*Continued*

TIME, IN HOURS, FOR LABOR ITEMS FOR EACH PROJECT AND FOR ALL PROJECTS

Farm project No.	Refilling trenches				Outlet protection			Miscellaneous
	Man hours	Team hours	Machine hours	Totals reduced to team hours + 1⅓ man hr.¶	Man hours	Team hours	Totals reduced to man hours	Man hours
Rolling Land								
1	160	65	...	92				
3	210	140	...	149				
7	130	110	...	104†				
8	310	210	...	221	40	10	50	200
10	560	350	...	385				
14	60	...	...	23	10	..	10	
15	430	400	...	361†				
17	90	...	20	94				
Totals	1,950	1,275	20	1,429	50	10	60	200
Flat Land								
2	250	200	...	194†	70	10	80	
4	180	...	...	67†	10	..	10	
5	120	80	...	85*	55	15	70‡	
6	180	120	...	127	30	15	45	
9	410	390	...	349†	20	..	20†	
11	440	285	...	307†				
12	170	...	85	319†	40	5	45†	
18	60	60	...	53				
Totals	1,810	1,135	85	1,501	225	45	270	
Peat Land								
13	225	...	...	84	10	..	10	270
16	70	...	...	26	..	..	..	84
Totals	295	...	...	110	10	..	10	354
Grand totals	4,055	2,410	105	3,040	285	55	340	554

* Partly estimated.

† Estimated.

‡ A small part estimated.

§ Horse-drawn machine—1 machine hour reckoned as equal to 4.4 man hours.

‖ Gas-power machine—1 machine hour reckoned as equal to 8.4 man hours.

¶ Total results indicated that each team hour also required 1⅓ man hours, hence the unit used.

TABLE VI

ENGINEERING AND SUPERVISION COST IN MONEY AND IN TIME PER MAN HOUR, PER ACRE, PER 1000 LINEAR FEET, PER TON AND PER CARLOAD OF TILE

Farm project No.	Cost in dollars							
	Total	Per hour	Per acre			Per		
			Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land								
1	$ 50.00	$1.25	$0.68	$3.33	$5.00	$5.56	$1.34	$20.08
3	104.35	0.80	1.37	7.45	7.45	16.60	3.38	50.90
7	163.17	0.88	1.36	8.16	20.40	16.88	2.60	39.06
8	215.75	0.70	0.91	3.85	3.85	7.86	1.12	16.87
10	342.76	1.96	2.14	8.57	26.37	27.47	4.20	62.42
14	56.05	0.75	16.01	28.03	56.05	33.97	7.55	113.23
15	947.20	0.61	1.89	5.57	7.89	16.87	3.08	46.14
17	214.07	1.65	1.54	6.12	6.12	13.79	1.12	16.72
Totals	$2,093.35							
Averages		$0.80	$1.60	$5.94	$8.14	$15.17	$2.30	$34.41
Flat Land								
2	$ 128.50	$0.48	$0.80	$0.80	$1.61	$3.60	$0.51	$ 7.67
4	39.00	0.49	0.98	1.11	7.80	9.15	2.25	33.77
5	234.82	0.78	1.27	1.96	2.35	9.15	1.06	15.94
6	157.20	0.68	1.31	1.31	1.66	7.95	1.84	27.65
9	216.08	1.66	2.27	2.27	6 75	4.65	1.03	15.46
11	625.00	1.01	2.08	4.01	8.22	11.31	1.39	20.83
12	722.25	0.86	2.83	7.22	9.63	12.90	1.33	19.96
18	42.32	1.21	6.03	8.46	16.93	12.82	2.69	40.48
Totals	$2,165.17							
Averages		$0.86	$1.86	$2.74	$4.65	$ 8.79	$1.21	$18.11
Peat Land								
13	$ 454.30	$1.01	$11.36	$16.23	$16.23	$31.83	$6.23	$ 93.48
16	212.84	1.33	10.64	14.19	14.19	51.04	11.34	170.14
Totals	$ 667.14							
Averages		$1.09	$11.12	$15.51	$15.51	$36.17	$7.28	$109.18
Grand totals	$4,925.66							
Grand averages		$0.86	$1.95	$4.15	$6.43	$12.23	$1.65	$26.41

TABLE VI—*Continued*

ENGINEERING AND SUPERVISION COST IN MONEY AND IN TIME PER MAN HOUR, PER ACRE, PER 1000 LINEAR FEET, PER TON AND PER CARLOAD OF TILE

Farm project No.	Time in hours: Total	Per acre: Of watershed on farm	Per acre: Drained	Per acre: Reclaimed	Per: 1000 lin. ft. of tile	Per: Ton of tile	Per: Carload of tile
Rolling Land							
1	40	0.55	2.67	4.00	4.55	1.07	16.06
3	130	1.71	9.29	9.29	20.68	4.22	63.41
7	185	1.54	9.25	23.12	19.14	2.95	44.26
8	310	1.31	5.54	5.54	11.30	1.62	24.24
10	175	1.09	4.37	13.46	14.02	2.14	31.88
14	75	21.43	37.50	75.00	45.45	10.10	150.00
15	1,560	3.12	9.18	13.00	27.79	5.07	75.99
17	130	0.94	3.71	3.71	8.37	0.68	10.16
Totals	2,605						
Averages		1.99	7.40	10.14	18.88	2.86	42.82
Flat Land							
2	270	1.69	1.69	3.38	7.57	1.08	16.13
4	80	2.00	2.29	16.00	18.78	4.62	68.97
5	300	1.62	2.50	3.00	11.69	1.36	20.37
6	230	1.92	1.92	2.42	11.63	2.70	40.42
9	130	1.37	1.37	4.06	2.80	0.62	9.30
11	620	2.07	3.97	8.16	11.22	1.38	20.67
12	840	3.29	8.40	11.20	15.00	1.55	23.21
18	35	5.00	7.00	14.00	10.61	2.23	33.33
Totals	2,505						
Averages		2.16	3.17	5.38	10.17	1.40	20.96
Peat Land							
13	450	11.25	16.07	16.07	31.52	6.17	92.59
16	160	8.00	10.67	10.67	38.37	8.52	128.00
Totals	610						
Averages		10.16	14.19	14.19	33.07	6.65	99.84
Grand totals	5,720						
Grand averages		2.26	4.82	7.47	14.20	1.92	30.67

TABLE VII

LINEAR FEET OF DIFFERENT SIZES OF TILE ON EACH PROJECT AND ON ALL PROJECTS

Farm project No.	4-in.	5-in.	6-in.	7-in.	8-in.	9-in.	10 in.	12-in.	14-in.	15-in.	16-in.	18-in.	20-in.	22-in.	Totals
Rolling Land															
1	3,000	3,600	500	900	800										8,800
3	2,710	630	770		2,175										6,285
7	2,386	745	2,502		2,365		1,270	400							9,668
8	10,173	7,790	2,850	1,190	800		300	2,000	200		1,500	640			27,443
10		7,953	951		1,200		1,214	1,160							12,478
14		1,650													1,650
15		41,540	6,191	1,750	1,150	1,300	400	2,500	1,110	155		35			56,131
17		5,638	3,475	700	555		1,100	2,177			1,880				15,525
Totals	18,269	69,546	17,239	4,540	9,045	1,300	4,284	8,237	1,310	155	3,380	675		...	137,980
Flat Land															
2	24,250	6,450								1,000	1,500	2,405			35,665
4	2,075	710	850	450	175										4,260
5	18,625	1,320	1,120								2,100	2,500			25,665
6	12,130	2,320	2,700		1,355		1,275								19,780
9	26,000	9,857	6,800		1,040		760	450	1,500						46,407
11		35,982	7,123		2,675		2,900	6,000	200			330		40	55,250
12		43,465	3,995	160	1,248		1,990	542	400	500	1,080	270	1,542	808	56,000
18		3,300													3,300
Totals	83,080	103,404	22,588	610	6,493		6,925	6,992	2,100	1,500	4,680	5,565	1,542	848	246,327
Peat Land															
13		11,925	400	700	1,250										14,275
16		4,170													4,170
Totals		16,095	400	700	1,250										18,445
Grand totals	101,349	189,045	40,227	5,850	16,788	1,300	11,209	15,229	3,410	1,655	8,060	6,240	1,542	848	402,752

TABLE VIII

LINEAR FEET OF TILE ON EACH PROJECT AND ON ALL PROJECTS (6-INCH AND LESS, AND OVER 6-INCH)

Farm project No.	6-inch and less				Over 6-inch				Grand total			
	Total	Per acre			Total	Per acre			Total	Per acre		
		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed
Rolling Land												
1	7,100	97	473	710	1,700	23	113	170	8,800	120	586	880
3	4,110	54	294	294	2,175	29	155	155	6,285	83	449	449
7	5,633	47	282	704	4,035	34	202	504	9,668	81	484	1,208
8	20,813	98	372	372	6,630	28	118	118	27,443	116	490	490
10	8,904	56	223	685	3574	22	89	275	12,478	78	312	960
14	1,650	471	825	1,650		..	...	...	1,650	471	825	1,650
15	47,731	95	281	398	8,400	17	49	70	56,131	112	330	468
17	9,113	66	260	260	6,412	46	183	183	15,525	112	443	443
Totals	105,054	...	...	...	32,926	..	...	...	137,980			
Averages		80	298	409		25	94	128		105	392	537
Flat Land												
2	30,700	192	192	384	4,965	31	31	62	35,665	223	223	446
4	3,635	91	104	727	625	16	18	125	4,260	107	122	852
5	21,065	114	176	211	4,600	25	38	46	25,665	139	214	257
6	17,150	143	143	181	2,630	22	22	28	19,780	165	165	209
9	42,657	449	449	1,333	3,750	39	39	117	46,407	488	488	1,450
11	43,105	144	276	567	12,145	40	78	160	55,250	184	354	727
12	47,460	186	475	633	8,540	33	85	114	56,000	219	560	747
18	3,300	471	660	1,320		..	..	...	3,300	471	660	1,320
Totals	209,072	...	...	...	37,255	..	..	...	246,327			
Averages		180	264	449		32	47	80		212	311	529
Peat Land												
13	12,325	308	440	440	1,950	49	70	70	14,275	357	510	510
16	4,170	208	278	278		..	..	...	4,170	208	278	278
Totals	16,495	...	...	...	1,950	..	..	...	18,445			
Averages		275	384	384		32	45	45		307	429	429
Grand totals	330,621	...	...	...	72,131	..	..	...	402,752			
Grand averages		131	279	432		29	61	94		160	340	526

TABLE IX

Weight of Tile on Each Project and on All Projects, Tons

Farm project No.	6-inch and less				Over 6-inch				Grand total			
	Total	Per acre			Total	Per acre			Total	Per acre		
		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed
Rolling Land												
1	25.90	0.35	1.73	2.59	11.40	0.16	0.76	1.14	37.30	0 51	2.49	3.73
3	14.50	0.19	1.03	1.03	16.31	0.22	1.17	1.17	30.81	0.41	2.20	2.20
7	22.65	0.19	1.13	2.83	40.01	0.33	2.00	5.00	62.66	0.52	3.13	7.83
8	75.93	0.32	1.36	1.36	115.94	0.49	2.07	2.07	191.87	0.81	3.43	3.43
10	38.93	0.24	0.96	2.99	42.73	0.27	1.08	3.29	81.66	0.51	2.04	6.28
14	7.43	2.12	3.72	7.43		...	...	...	7.43	2.12	3.72	7.43
15	198.47	0.40	1.17	1.65	109.43	0.22	0.64	0.91	307.90	0.62	1.81	2.56
17	51.00	0.37	1.46	1.46	141.00	1.01	4.03	4.03	192.00	1.38	5.49	5.49
Totals	434.81	...	...	...	476.82	...	...	...	911.63			
Averages		0.33	1.24	1.69		0 36	1.35	1.85		0.69	2.59	3.54
Flat Land												
2	98.55	0.62	0.62	1.24	152.61	0.95	0.95	1.90	251.16	1.57	1.57	3.14
4	13.32	0.33	0 38	2.66	4.01	0.10	0.11	0.80	17.33	0.43	0.49	3.46
5	81.94	0.44	0.68	0.82	139.00	0.76	1.16	1.40	220.94	1.20	1.84	2.22
6	59.17	0.49	0.49	0.62	26.10	0.22	0.22	0.28	85.27	0.71	0.71	0.90
9	151.43	1.60	1.60	4.73	58.25	0.61	0.61	1.82	209.68	2.21	2.21	6.55
11	226.20	0.75	1.45	2.98	224.10	0.75	1.44	2.95	450.30	1.50	2.89	5.93
12	243.30	0.95	2.43	3.24	299.59	1.18	3.00	4.00	542.89	2.13	5.43	7.24
18	15.68	2.24	3.14	1.57		...	...	...	15.68	2.24	3.14	1.57
Totals	889.59	...	...	...	903.66	...	...	...	1,793.25			
Averages		0.77	1.13	1.91		0.78	1.14	1.94		1.55	2.27	3.85
Peat Land												
13	57.23	1.43	2.04	2.04	15.70	0.39	0 56	0 56	72.93	1.82	2.60	2.60
16	18.77	0.94	1.25	1.25		...	...	...	18.77	0.94	1.25	1.25
Totals	76.00	...	...	...	15.70	...	...	...	91.70			
Averages		1.27	1.77	1.77		0.26	0.37	0.37	...	1.53	2.14	2.14
Grand totals	1,400.40	...	...	...	1,396.18	...	...	...	2,796.58			
Grand averages		0.55	1.18	1.83		0.55	1.18	1.83		1.10	2.36	3.65

TABLE X

WEIGHT OF TILE ON EACH PROJECT AND ON ALL PROJECTS, IN CARLOADS (30,000 LBS.)

Farm project No.	6-inch and less				Over 6 inch				Grand total			
	Total	Per acre			Total	Per acre			Total	Per acre		
		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed		Of watershed on farm	Drained	Reclaimed
Rolling Land												
1	1.73	0 02	0.12	0.17	0.76	0.01	0.05	0.08	2.49	0.03	0.17	0.25
3	0.96	0.01	0.07	0.07	1.09	0.02	0.08	0.08	2.05	0.03	0.15	0.15
7	1.51	0 01	0.08	0.19	2.67	0.02	0.13	0.33	4.18	0.03	0.21	0.52
8	5.06	0.02	0.09	0.09	7.73	0.03	0.14	0.14	12.79	0.05	0.23	0.23
10	2.64	0.02	0.07	0.20	2.85	0.02	0.07	0.22	5.49	0.04	0.14	0.42
14	0.50	0.14	0.25	0.50		...	...	...	0.50	0.14	0.25	0.50
15	13.23	0.03	0.08	0.11	7.30	0 01	0.04	0 06	20.53	0 04	0.12	0.17
17	3.40	0.02	0.10	0.10	9.40	0.07	0.27	0.27	12.80	0.09	0 37	0.37
Totals	29.03	...	...	...	31.80	...	...	...	60.83			
Averages		0.02	0.08	0.11		0.02	0.09	0.12		0.04	0.17	0.23
Flat Land												
2	6.57	0.04	0.04	0.08	10.17	0.06	0.06	0.13	16.74	0.10	0.10	0.21
4	0.89	0.02	0.02	0.18	0.27	0.01	0.01	0.05	1.16	0.03	0.03	0.23
5	5.46	0.03	0.05	0.05	9.27	0 05	0.08	0.09	14 73	0.08	0.12	0.15
6	3.95	0.03	0.03	0.04	1.74	0.02	0.02	0.02	5.69	0.05	0.05	0.06
9	10.10	0.11	0.11	0.32	3.88	0.04	0.04	0.12	13.98	0.15	0.15	0.44
11	15.08	0.05	0.10	0.20	14.92	0 05	0.10	0.20	30.06	0.10	0.19	0.40
12	16.21	0 06	0.16	0.22	19.98	0.08	0.20	0.26	36.19	0.14	0.36	0.48
18	1.05	0.15	0.21	0.42		...	...	...	1.05	0.15	0.21	0.42
Totals	59.31	...	...	...	60.23	...	...	...	119.54			
Averages		0.05	0.07	0.13		0.05	0.08	0.13		0.10	0.15	0.26
Peat Land												
13	3.81	0.09	0.14	0.14	0.14	0.03	0.04	0.04	4.86	0.12	0.18	0.18
16	1.25	0.06	0.08	0.08		...	...	...	1.25	0.06	0.08	0.08
Totals	5.06	...	...	...	1.05	...	...	...	6.11			
Averages		0.08	0.12	0.12		0.02	0.02	0.02		0.10	0.14	0 14
Grand totals	93.40	...	...	...	93.08	...	...	...	186.48			
Grand averages		0.04	0.09	0.12		0.04	0.08	0.12		0.08	0.17	0.24

TABLE XI

ACTUAL MONEY COST OF TILE PER ACRE; AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Total cost	Per acre			Per		
		Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land							
1	$ 171.65	$ 2.35	$11.44	$17.17	$19.51	$4.60	$ 68.94
3	166.97	2.20	11.93	11.93	26.59	5.42	81.45
7	407.03	3.39	20.35	50.88	42.10	6.50	97.45
8	1,198.45	5.06	21.40	21.40	43.67	6 25	93.69
10	278.10	1.74	6.95	21.39	22.29	3.41	50.65
14	54.12	15.46	27.06	54.12	32.80	7.29	109.33
15	2,589.36	5.18	15.23	21.58	46.13	8.41	126.13
17	1,278.11	9.20	36.52	36.52	82.33	6.66	99.99
Totals	$6,143.79						
Averages		$ 4.70	$17.45	$23.91	$44.53	$6.74	$101.00
Flat Land							
2	$ 1,833 19	$11.46	$11.46	$22.92	$51.40	$7.30	$109.48
4	86.91	2.17	2.48	17.38	20.40	5.02	75.25
5	1,589.13	8.59	13.24	15.89	61.92	7.19	107.88
6	406.17	3.38	3.38	4.28	20.53	4.76	71.43
9	1,211.25	12.75	12.75	37.85	26.10	5.78	86.65
11	3,126.58	10.42	20.04	41.14	56.59	6.94	104.22
12	4,138.24	16.23	41.38	55.18	73.90	7.62	114.35
18	68.38	9.77	13.68	27.35	20.72	4.36	65.44
Totals	$12,459.85						
Averages		$10.72	$15.75	$26.77	$50.58	$6.95	$104.23
Peat Land							
13	$ 498.41	$12.46	$17.80	$17.80	$34.91	$6.83	$102.99
16	136.78	6.84	9.12	9.12	32.80	7.29	109.34
Totals	$ 635.19						
Averages		$10.59	$14.77	$14.77	$34.44	$6.93	$103.96
Grand totals	$19,238.83						
Grand averages		$ 7.60	$16.22	$25.13	$47.77	$6.46	$103.17

TABLE XII

CARLOADS AND TONS OF TILE, MILES OF RAILROAD AND OF TEAM OR TRUCK HAUL, CARLOAD MILES OF RAILROAD HAUL, AND TON MILES OF TEAM OR TRUCK HAUL

Farm project No.	Total carloads of tile	Total miles of railroad haul	Total carload miles of railroad haul	Total tons of tile	Total miles of team or truck haul	Total ton miles of team or truck haul
Rolling Land						
1	2.49	140	348.60	37.30	0.50	18.65
3	2.05	145	297.25	30.81	5.00	154.05
7	4.18	295	1,233.10	62.66	1.50	93.99
8	12.79	105	1,342.95	191.87	3.00	575.61
10	5.49	517	2,838.33	81.66	7.00	571.62
14	0.50	...		7.43	13.00	96.59
15	20.53	143	2,953.79	307.90	3.50	1,077.65
17	12.80	88	1,126.40	192.00	5.00	960.00
Totals	60.83	1,433	10,122.42	911.63	38.50	3,548.16
Flat Land						
2	16.74	431	7,214.94	251.16	2.50	627.90
4	1.16	150	174.00	17.33	2.00	34.66
5	14.73	348	5,126.04	220.94	2.00	441.88
6	5.69	10	56.90	85.27	8.00	682.16
9	13.98	398	5,564.04	209.68	0.50	104.84
11	30.00	44	1,320.00	450.30	1.00	450.30
12	36.19	44	1,592.36	542.89	2.50	1,357.23
18	1.05	336	352.80	15.68	1.00	15.68
Totals	119.54	1,761	21,401.08	1,793.25	19.50	3,714.65
Peat Land						
13	4.86	110	534.60	72.93	4.25	309.95
16	1.25	201	251.25	18.77	0.25	4.69
Totals	6.11	311	785.85	91.70	4.50	314.64
Grand totals	186.48	3,505	32,309.35	2,976.58	62.50	7,577.45

TABLE XIII

ACTUAL MONEY COST OF FREIGHT ON TILE PER ACRE, PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE; AND PER CARLOAD MILE OF RAILROAD HAUL

Farm project No.	Total cost	Per acre			Per			
		Of watershed on farm	Drained	Reclaimed	1000 linear feet of tile	Ton of tile	Carload of tile	Carload mile of railroad haul
Rolling Land								
1.....	$ 55.97	$0.77	$3.73	$ 5.60	$ 6.36	$1.50	$22.48	$0.16
3.....	37.02	0.49	2.64	2.64	5.89	1.20	18.06	0.12
7.....	150.39	1.25	7.52	18.80	15.56	2.40	25.23	0.12
8.....	277.51	1.17	4.96	4.96	10.11	1.45	21.70	0.21
10.....	301.79	2.14	8.57	26.37	27.47	4.20	62.42	0.11
14.....	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15.....	369.48	0.74	2.17	3.08	6.58	1.20	18.00	0.13
17.....	294.29	2.12	8.41	8.41	18.96	1.52	22.99	0.26
Totals	$1,527.42							
Averages...		$1.17	$4.34	$ 5.94	$11.07	$1.68	$25.11	$0.15
Flat Land								
2.....	$867.68	$ 5.42	$ 5.42	$10.85	$24.33	$3.45	$51.82	$0.12
4.....	20.79	0.52	0.59	4.16	4.88	1.20	18.00	0.12
5.....	572.69	3.10	4.77	5 73	22.31	2.59	38.88	0.11
6.....	46.03	0.38	0.38	0.49	2.33	0.54	8.10	0.08
9.....	587.16	6.18	6.18	18.35	12.65	2.80	42.00	0.11
11.....	320.65	1.07	2.06	4.22	5.80	0.71	10.69	0.24
12.....	386.74	1.52	3.87	5.16	6.91	0.71	10.69	0.24
18.....	72.62	10.37	14.52	29.05	22.01	4.63	69.49	0.21
Totals	$2,874.36							
Averages...		$ 2.47	$ 3.63	$ 6.17	$11.67	$1.60	$24.05	$0.13
Peat Land								
13.....	$164.86	$4.12	$5.89	$5.89	$11.55	$2.26	$33.92	$0.31
16.....	43.16	2.16	2.88	2.88	10.35	2.30	34.50	0.17
Totals	$208.02							
Averages...		$3.47	$4.84	$4.84	$11.28	$2.27	$34.05	$0.26
Grand totals	$4,568.83							
Grand averages.....		$1.81	$3.85	$5.97	$11.34	$1.53	$24.50	$0.14

TABLE XIV

COST IN MONEY AND IN TIME OF HAUL AND DISTRIBUTION OF TILE PER MAN HOUR, PER ACRE, AND PER 1000 LINEAR FEET, PER TON AND PER CARLOAD OF TILE, AND PER TON MILE OF TEAM OR TRUCK HAUL

Farm project No.	Total cost	Per man hour	Cost in dollars: Per acre: Of watershed on farm	Per acre: Drained	Per acre: Reclaimed	Per: 1000 lin. ft. of tile	Per: Ton of tile	Per: Carload of tile	Per: Ton mile of team or truck haul
Rolling Land									
1	$ 24.48	$0.19	$0.34	$ 1.63	$ 2.45	$ 2.72	$0.66	$ 9.83	$1.31
3	68.28	0.18	0.90	4.88	4.88	10.86	2.22	33.31	0.44
7	66.88	0.20	0.56	3.34	8.36	6.92	1.07	16.01	0.71
8	198.00	0.25	0.84	3.54	3.54	7.22	1.03	15.48	0.34
10	133.10	0.20	0.83	3.30	10.24	10.67	1.63	24.24	0.23
14	30.00	0.50	8.57	15.00	30.00	18.18	4.04	60.60	0.31
15	500.30	0.32	1.00	2.94	4.17	8.91	1.62	24.37	0.46
17	330.64	0.30	2.38	9.45	9.45	21.30	1.72	25.83	0.34
Totals	$1,351.68								
Averages		$0.27	$1.03	$ 3.84	$ 5.26	$ 9.89	$1.48	$22.22	$0.38
Flat Land									
2	$ 371.87	$0.29	$2.32	$2.32	$ 4.65	$10.43	$1.48	$22.21	$0.59
4	10.13	0.23	0.25	0.29	2.03	0.95	0.58	0.88	0.23
5	180.52	0.23	0.98	1.50	1.81	3.52	0.41	6.13	0.20
6	182.00	0.18	1.52	1.52	1.92	9.20	2.26	33.90	0.28
9	118.25	0.59	1.24	1.24	3.70	2.55	0.56	8.46	1.13
11	292.72	0.35	0.98	1.88	3.85	5.30	0.65	9.76	0.65
12	899.22	0.33	3.53	8.99	11.99	16.06	1.66	24.85	0.66
18	10.20	0.41	1.46	2.04	4.08	3.09	0.65	9.76	0.65
Totals	$2,064.91								
Averages		$0.35	$1.78	$2.61	$ 4.44	$ 8.38	$1.15	$17.28	$0.56
Peat Land									
13	$ 122.40	$0.29	$3.06	$4.37	$4.37	$8.57	$1.68	$25.19	$0.39
16	18.00	0.45	0.90	1.20	1.20	4.32	0.96	14.38	3.84
Totals	$ 140.40								
Averages		$0.31	$2.34	$3.27	$3.27	$7.61	$1.53	$22.98	$0.45
Grand totals	$3,556.99								
Grand averages		$0.31	$1.41	$3.00	$4.65	$8.83	$1.19	$19.07	$0.47

TABLE XIV—*Continued*

COST IN MONEY AND IN TIME OF HAUL AND DISTRIBUTION OF TILE PER MAN HOUR, PER ACRE, AND PER 1000 LINEAR FEET, PER TON AND PER CARLOAD OF TILE, AND PER TON MILE OF TEAM OR TRUCK HAUL

Farm project No.	Time in hours							
	Total man hours	Per acre			Per			
		Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile	Ton mile of team or truck haul
Rolling Land								
1.....	130	1.78	8.67	13.00	14.77	3.49	52.21	6.97
3.....	380	5.00	27.14	27.14	60.46	12.33	185.37	2.46
7.....	340	2.83	17.00	42.50	35.17	5.43	81.34	3.62
8.....	790	3.33	14.11	14.11	28.79	4.12	61.77	1.37
0.....	670	4.19	16.75	51.54	53.69	8.20	122.04	1.17
4.....	60	17.14	30.00	60.00	36.36	8.08	120.00	0.62
5.....	1,540	3.08	9.06	12.83	27.44	5.00	75.01	1.43
7.....	1,100	7.91	31.43	31.43	70.85	5.73	85.94	1.15
Totals.....	5,010							...
Averages....		3.83	14.23	19.49	36.31	5.50	82.36	1.41
Flat Land								
2.....	1,300	8.12	8.12	16.25	36.45	5.18	77.66	2.07
4.....	45	1.12	1.29	9.00	10.56	2.60	38.79	1.30
5.....	780	4.22	6.50	7.80	30.39	3.53	52.95	1.77
6.....	1,040	8.67	8.67	10.94	52.58	12.20	182.77	1.52
9.....	200	2.10	2.10	6.25	4.31	0.95	14.31	1.91
1.....	840	2.80	5.38	11.05	15.20	1.87	28.00	1.87
2.....	2,730	10.70	27.30	36.40	48.75	5.03	75.44	2.01
8.....	25	3.57	5.00	10.00	7.57	1.59	23.81	1.59
Totals.....	5,960							...
Averages....		5.13	7.53	12.80	24.20	3.32	49.86	1.60
Peat Land								
3.....	420	10.50	15.00	15.00	29.42	5.76	86.42	1.36
6.....	40	2.00	2.67	2.67	9.59	2.13	32.00	8.53
Totals.....	460							...
Averages....		7.67	10.70	10.70	24.94	5.02	75.29	1.46
Grand totals..	11,430							...
Grand averages		4.52	9.64	14.93	28.38	3.84	61.29	1.51

TABLE XV

COST IN MONEY AND IN TIME OF TRENCHING, LAYING, AND BLINDING PER MAN HOUR, PER ACRE PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Cost in dollars							
	Total	Per hour	Per acre			Per		
			Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land								
1	$ 256.00	$0.20	$3.51	$17.07	$25.60	$29.09	$6.86	$102.81
3	316.50	0.35	4.16	22.61	22.61	50.36	10.27	154.39
7	415.97	0.27	3.47	20.80	52.00	43.03	6.64	99.59
8	1,424.09	0.36	6.01	25.43	25.43	51.89	7.42	111.34
10	1,515.76	0.49	9.47	37.89	116.60	121.48	18.56	276.04
14	90.00	0.90	25.71	45.00	90.00	54.54	12.12	181.82
15	4,296.63	0.79	8.59	25.27	35.81	76.55	13.95	209.29
17	1,561.23	0.66	11.23	44.61	44.61	100.56	8.13	121.97
Totals	$9,876.18							
Averages		$0.53	$7.55	$28.06	$38.43	$71.58	$10.83	$162.36
Flat Land								
2	$1,378.34	$0.17	$8.62	$8.62	$17.23	$38.65	$5.49	$82.31
4	221.35	0.41	5.53	6.32	44.27	5.20	12.77	19.16
5	1,115.00	0.33	6.03	9.29	11.15	43.44	5.05	75.70
6	670.37	0.33	5.59	5.59	7.06	33.89	7.86	117.90
9	2,142.30	0.26	22.55	22.55	66.95	46.16	10.22	153.25
11	2,806.29	0.28	9.35	17.99	36.92	50.79	6.23	93.54
12	3,656.48	0.38	14.34	36.56	48.75	65.29	6.74	101.04
18	80.50	0.35	11.50	16.10	32.20	24.39	5.13	77.03
Totals	$12,070.63							
Averages		$0.29	$10.39	$15.26	$25.93	$49.00	$6.73	$100.98
Peat Land								
13	$1,110.08	$0.86	$27.75	$39.65	$39.65	$77.76	$15.22	$228.41
16	376.00	0.77	18.80	25.07	25.07	9.02	20.04	300.56
Totals	$1,486.08							
Averages		$0.84	$24.77	$34.56	$34.56	$80.57	$16.21	$243.22
Grand totals	$23,432.89							
Grand averages		$0.37	$9.26	$19.76	$30.61	$58.18	$7.87	$125.66

TABLE XV—*Continued*

COST IN MONEY AND IN TIME OF TRENCHING, LAYING, AND BLINDING PER MAN HOUR, PER ACRE, PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Total	Time in hours					
		Per acre			Per		
		Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land							
1	1,300	17.81	86.67	130.00	147.73	34.85	522.04
3	910	11.97	65 00	65.00	144.79	29.53	443.90
7	1,555	12.96	77.75	194.38	160.84	24.82	372.01
8	4,010	16.92	71.61	71.61	146.12	20.89	313 53
10	3,072	19.20	76.80	236.31	246.19	37.62	559.56
14	100	28.57	50.00	100.00	60.60	13.46	200.00
15	5,420	10.84	31.88	45.17	96.56	17.60	264.00
17	2,360	16.98	67.43	67.43	152.01	12.29	184.38
Totals	18,727						
Averages		14.31	53.20	72.87	135.72	20.54	307.86
Flat Land							
2	8,270	51.69	51.69	103 37	231.88	32.93	494.03
4	540	13.50	15.43	108.00	126.76	31.16	465.52
5	3,330	18.00	27.75	33.30	129.75	15 07	226.07
6	2,030	16.92	16.92	21.37	102.63	23.81	356.77
9	8,180	86.11	86.11	255.62	176.27	39.01	585.12
11	9,880	32.93	63.33	130.00	178.82	21.94	329.33
12	9,720	38.12	97.20	129.60	173.57	17.90	268.58
18	230	32.86	46.00	92.00	69.70	14.67	219.05
Totals	42,180						
Averages		36.30	53.32	90.61	171.24	23.52	352.85
Peat Land							
13	1,288	32.20	46.00	46.00	90.23	17.66	265.02
16	488	24.40	32.53	32.53	117.03	26.00	390,40
Totals	1,776						
Averages		29.60	41.30	41.30	96.29	19.37	290.67
Grand totals	62,683						
Grand averages		24.77	52.85	81.89	155.64	21.06	336.14

TABLE XVI

WORK UNITS, MAN HOURS, SIZE OF TILE, AND AVERAGE CUT FOR EACH PROJECT AND FOR ALL PROJECTS IN EASY DIGGING

Farm project No.	Tile			Work units			Total man hours labor
	Inner diameter, inches	Average cut, feet	Total linear feet	Per linear foot	Total per item	Grand total per project	
13	6 or under	3.56	12,325	6.2	76,415.0		
	7	4.80	700	13.5	9,450.0		
	8	4.20	1,250	11.8	14,750.0	100,615.0	1,288
16	5	3.41	4,170	5.7	23,769.0	23,769 0	488
Totals—easy digging						124,384.0	1,776
Work units per man hour—easy digging						70.0	

TABLE XVII

WORK UNITS, MAN HOURS, SIZE OF TILE, AND AVERAGE CUT FOR EACH PROJECT AND FOR ALL PROJECTS IN AVERAGE DIGGING

Farm project No.	Tile			Work units			Total man hours labo
	Inner diameter, inches	Average cut, feet	Total linear feet	Per linear foot	Total per item	Grand total per project	
1.....	6 or under	3.34	7,100	5.5	39,050.0		
	7	3.77	900	8.2	7,380.0		
	8	4.06	800	11.0	8,800.0	55,230.0	1,30
2.....	6 or under	2.80	30,700	4.4	135,080.0		
	15	6.50	1,000	51.7	51,700.0		
	16	6.50	1,500	55.0	82,500.0		
	18	6.50	2,465	62.3	153,569.5	422,849.5	8,27
3.....	6 or under	3.05	4,110	4.6	18,906.0		
	8	4.50	2,175	13.6	29,580.0	62,460.0	91
4.....	6 or under	3.31	3,635	5.5	19,992.5		
	7	5.05	450	14.8	6,660.0		
	8	5.05	175	16.8	2,940.0	29,592.5	54
5.....	6 or under	3.13	21,065	4.7	99,005.5		
	16	5.20	2,100	35.8	75,180.0		
	18	5.50	2,500	44.6	111,500.0	285,685.5	3,33
6.....	6 or under	3.14	17,150	4.7	80,605.0		
	8	2.70	1,355	5.7	13,423.5		
	10	3.22	1,275	8.0	10,200.0	104,228.5	2,03
8.....	6 or under	3.31	20,813	5.5	114,471.5		
	7	3.55	1,190	7.1	8,449.0		
	8	3.90	800	10.0	8,000.0		
	10	4.20	300	14.2	4,260.0		
	12	4.03	2,000	15.5	31,000.0		
	14	4.30	200	21.8	4,360.0		
	16	5.00	1,500	32.8	49,200.0		
	18	3.20	640	15.7	10,048.0	229,788.5	4,01
9.....	6 or under	3.29	42,657	5.5	234,613.5		
	8	3.34	1,040	7.0	7,280.0		
	10	3.30	760	8.4	6,384.0		
	12	3.60	450	12.0	5,400.0		
	14	4.70	1,500	26.0	39,000.0	292,677.5	8,18
Totals for average digging, carried forward.....						1,468,538.0	28,57

TABLE XVII—*Continued*

WORK UNITS, MAN HOURS, SIZE OF TILE, AND AVERAGE CUT FOR EACH PROJECT AND FOR ALL PROJECTS IN AVERAGE DIGGING

Farm project No.	Tile			Work units			Total man hours labor
	Inner diameter, inches	Average cut, feet	Total linear feet	Per linear foot	Total per item	Grand total per project	
Totals brought forward						1,468,538.0	28,570
11	6 or under	3.53	43,105	6.1	262,940.5		
	8	4.85	2,675	15.6	41,730.0		
	10	5.39	2,900	24.2	70,180.0		
	12	5.55	6,000	30.3	181,800.0		
	14	5.52	200	35.5	7,100.0		
	18	6.11	330	55.0	18,150.0		
	22	4.34	40	35.5	1,420.0	583,320.5	9,880
12	6 or under	2.84	47,460	4.4	208,824.0		
	7	3.92	160	8.9	1,424.0		
	8	4.11	1,248	11.4	14,227.2		
	10	4.94	1,990	20.3	40,397.0		
	12	5.92	542	34.3	18,590.6		
	14	5.21	400	31.8	12,720.0		
	15	5.46	500	36.8	18,400.0		
	16	6.03	1,080	47.8	51,624.0		
	18	7.29	270	78.3	21,141.0		
	20	7.12	1,542	83.0	127,986.0		
	22	5.37	808	53.4	43,147.2	558,481.0	9,720
14	5	3.35	1,650	5.5	9,075.0	9,075.0	100
15	6 or under	3.54	47,731	6.2	295,932.2		
	7	5.41	1,750	17.0	29,750.0		
	8	4.93	1,150	16.0	18,400.0		
	9	5.19	1,300	20.2	26,260.0		
	10	4.74	400	18.7	7,480.0		
	12	4.53	2,500	20.0	50,000.0		
	14	5.00	1,110	29.7	32,967.0		
	15	3.47	190	15.2	2,888.0		
	18	5.50	35	44.6	1,551.0	465,228.2	5,420
17	6 or under	3.91	9,113	7.6	69,258.8		
	7	4.05	700	9.5	6,650.0		
	8	3.93	555	10.1	5,605.5		
	10	4.49	1,100	16.5	19,585.5		
	12	5.09	2,177	25.3	55,078.1		
	16	7.28	1,880	68.5	128,780.0	284,957.9	2,360
18	5	3.43	3,300	5.8	19,140.0	19,140.0	230
Totals—average digging						3,388,740.6	56,280
Work units per man hour—average digging						60.2	
Or practically						60.0	

TABLE XVIII

WORK UNITS, MAN HOURS, SIZE OF TILE, AND AVERAGE CUT FOR EACH PROJECT AND FOR ALL PROJECTS IN HARD DIGGING

Farm project No.	Tile		Work units				Total man hours labor
	Inner diameter, inches	Average cut, feet	Total linear feet	Per linear foot	Total per item	Grand total per project	
7.....	6 or under	3.19	5,633	5.0	28,165.0		
	8	4.15	2,365	11.5	27,197.5		
	10	4.10	1,270	13.5	17,145.0		
	12	3.00	400	9.0	3,600.0	76,107.5	1,555
10.....	6 or under	3.64	8,904	6.3	56,095.2		
	8	4.52	1,200	13.8	16,560.0		
	10	4.79	1,214	19.4	23,351.6		
	12	4.76	1,160	22.0	25,520.0	121,526.8	3,072
Totals—hard digging						197,634.3	4,627
Work units per man hour—hard digging.....						43.0	

TABLE XIX

SHOWING FACTORS ENTERING INTO COMPUTATION OF WORK UNITS PER LINEAR FOOT OF TRENCH
Kind of Tile—Clay or Concrete; Size of Tile—10-inch

D	T	d	Y	Y_1	A	y	g	G	g+G	A(g+G)	a	s	as	asD	Work units per lin. ft. A(g+G) + asD
3.....	1.44	1.15	2.425	0.575	3.66	1.26	0.44	1.35	1.79	6.55	0.24	1⅛	0.27	0.81	7.36
4.....	1.56		3.425		5.16	1.55	0.53	1.77	2.30	11.87				1.08	12.95
5.....	1.68		4.425		6.78	1.82	0.62	2.19	2.81	19.05				1.35	20.40
6.....	1.80		5.425		8.52	2.07	0.68	2.59	3.27	27.86				1.62	29.48
7.....	1.92		6.425		10.38	2.32	0.76	2.98	3.74	38.82				1.89	40.71
8.....	2.04		7.425		12.36	2.56	0.84	3.36	4.20	51.91				2.16	54.07
9.....	2.16		8.425		14.46	2.79	0.90	3.74	4.64	67.09				2.43	69.52
10.....	2.28		9.425		16.68	3.02	0.97	4.10	5.07	84.56				2.70	87.26
11.....	2.40		10.425		19.02	3.24	1.03	4.45	5.48	104.23				2.97	107.20
12.....	2.52	1.15	11.425	0.575	21.48	3.47	1.11	4.82	5.93	127.38	0.24	1⅛	0.27	3.24	130.62

Note: Values in columns d, Y_1, a, s, as, are the same for each item as those shown in the first and last items.

TABLE XX

WORK UNITS PER LINEAR FOOT OF TRENCH FOR SIZES OF TILE 4- TO 24-INCH AND FOR DEPTHS OF TRENCH FROM 3 TO 12 FEET

Diam. of tile	Work units per linear foot for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	4.39	7.93	12.72	18.81	26.37	35.60	46.43	59.42	73.80	90.57
8.....	5.74	10.47	16.33	24.59	33.52	44.45	57.74	72.85	90.28	109.90
10.....	7.36	12.95	20.40	29.48	40.71	54.07	69.52	87.26	107.20	130.62
12.....	9.01	15.67	24.16	35.20	48.39	63.68	81.59	101.90	125.24	150.90
14.....	10.65	18.58	28.59	41.00	56.08	73.64	93.91	117.00	142.51	172.21
16.....	12.37	21.31	32.77	46.91	63.79	83.51	106.21	132.43	160.87	183.29
18.....	14.03	24.19	37.09	52.97	71.94	93.31	118.88	147.64	179.31	214.64
20.....	15.93	27.19	41.57	59.18	79.99	104.20	132.15	163.21	197.93	237.27
22.....	17.75	30.37	46.27	65.57	88.27	115.05	145.16	179.06	217.42	259.18
24.....	19.74	33.41	50.82	72.07	97.06	125.59	158.55	195.33	236.24	281.73

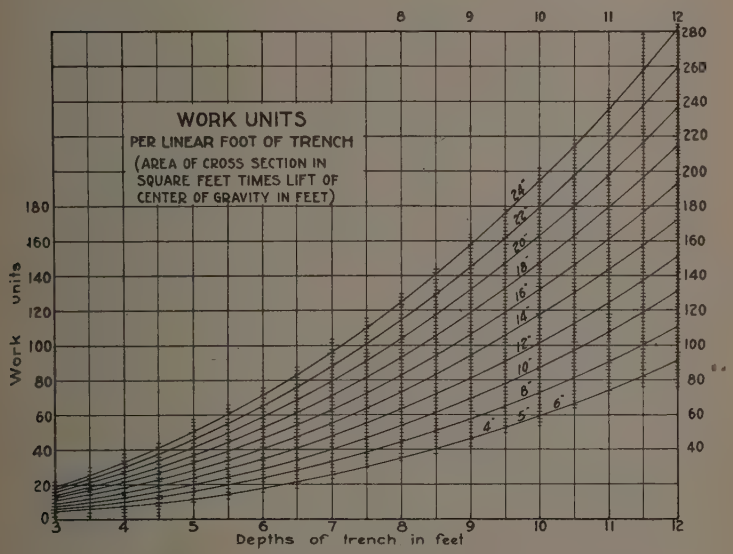


Fig. 20. Curves Showing Data in Table XX

TABLE XXI

HOURS REQUIRED TO DIG 100 LINEAR FEET OF TRENCH FOR SIZES OF TILE FROM 4-INCH TO 24-INCH, AND FOR DEPTHS OF TRENCH FROM 3 FEET TO 12 FEET

(Easy Digging—70 Work Units per Hour. Average of 2 Projects Only)

Diam. of tile	Hours per linear foot for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	6.27	11.33	18.17	26.87	37.67	50.86	66.33	84.89	105.43	129.3
8.....	8.20	14.96	23.33	35.13	47.89	63.50	82.19	104.07	128.97	157.0
10.....	10.51	18.50	29.14	42.11	58.16	77.24	99.31	124.66	153.14	187.7
12.....	12.87	22.39	34.51	50.29	69.13	90.97	116.56	145.57	178.91	215.5
14.....	15.21	26.54	40.84	58.57	80.11	105.20	134.16	167.14	203.59	246.0
16.....	17.67	30.44	46.81	67.01	91.13	119.30	151.73	189.19	229.81	276.1
18.....	20.04	34.56	52.99	75.67	102.77	133.30	169.83	210.91	256.16	306.6
20.....	22.76	38.84	59.39	84.54	114.27	148.86	188.79	233.16	282.76	338.9
22.....	25.36	43.39	66.10	93.67	126.10	164.36	207.37	255.80	310.60	370.2
24.....	28.20	47.73	72.60	102.96	138.66	179.41	226.50	279.04	337.49	402.4

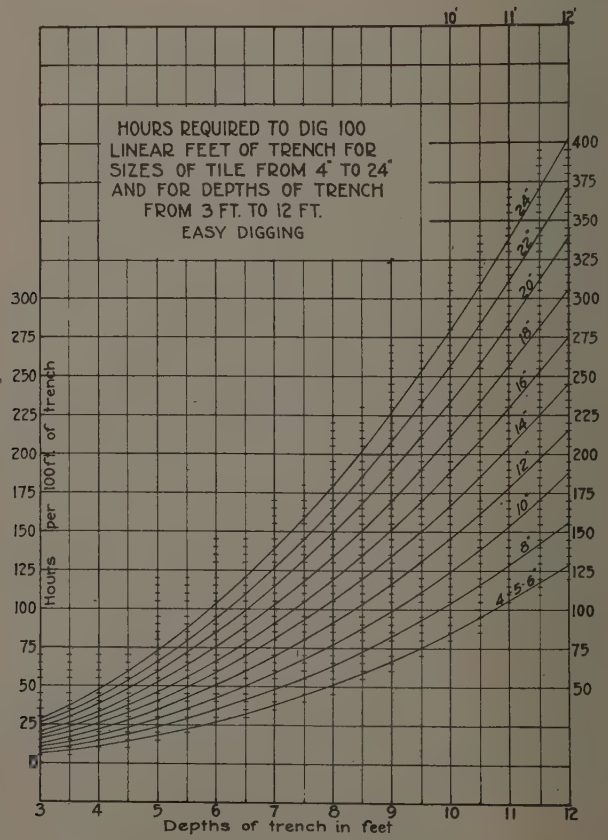


Fig. 21. Curves Showing Data in Table XXI

TABLE XXII

HOURS REQUIRED TO DIG 100 LINEAR FEET OF TRENCH FOR SIZES OF TILE FROM 4-INCH TO 24-INCH, AND FOR DEPTHS OF TRENCH FROM 3 FEET TO 12 FEET

(Average Digging—60 Work Units per Hour. Average of 14 Projects)

Diam. of tile	Hours per 100 linear feet for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	7.32	13.22	21.20	31.35	43.95	59.33	77.38	99.03	123.00	150.95
8.....	9.57	17.45	27.22	40.98	55.87	74.08	96.23	121.42	150.47	183.17
10.....	12.27	21.58	34.00	49.13	67.85	90.12	115.87	145.43	178.67	217.70
12.....	15.02	26.12	40.27	58.67	80.65	106.13	135.97	169.67	208.73	251.50
14.....	17.75	30.97	47.65	68.33	93.47	122.73	156.52	195.00	237.09	287.04
16.....	20.62	35.52	54.62	78.18	106.32	139.18	177.02	220.72	268.12	322.15
18.....	23.38	40.32	61.82	88.28	119.90	155.52	198.13	246.07	298.85	357.73
20.....	26.55	45.32	69.28	98.63	133.32	173.67	220.25	272.02	329.88	395.45
22.....	29.58	50.62	77.12	109.28	147.12	191.75	241.93	298.43	362.37	431.97
24.....	32.90	55.68	84.70	120.12	161.77	209.32	264.25	325.50	393.73	469.55

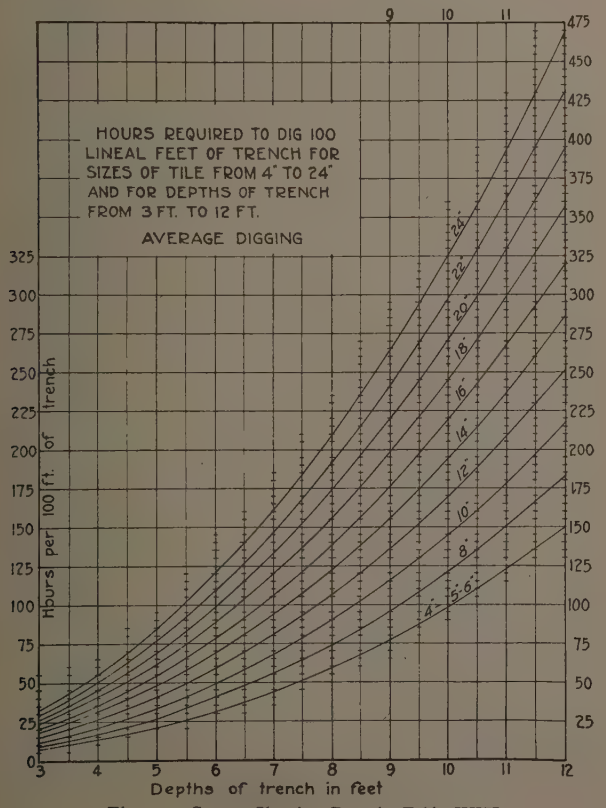


Fig. 22. Curves Showing Data in Table XXII

TABLE XXIII

HOURS REQUIRED TO DIG 100 LINEAR FEET OF TRENCH FOR SIZES OF TILE FROM 4-INCH TO 24-INCH, AND FOR DEPTHS OF TRENCH FROM 3 FEET TO 12 FEET

(Hard Digging—43 Work Units per Hour. Average of 2 Projects Only)

Diam. of tile	Hours per 100 linear feet for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	10.21	18.44	29.58	43.74	61.33	82.79	107.97	138.19	171.63	210.63
8.....	13.35	24.35	37.98	57.19	77.95	103.37	134.28	169.42	209.95	255.58
10.....	17.12	30.12	47.44	68.56	94.67	125.74	161.67	202.93	249.30	303.76
12.....	20.95	36.44	56.19	81.86	112.53	148.09	189 74	236.98	291.26	350.93
14.....	24.77	43.21	66.49	95.35	130.42	171.26	218.40	272.09	331.42	400.49
16.....	28.77	49.56	76.21	109.09	148.35	194.21	247.00	307.97	374.12	449.51
18.....	32.63	56.26	86.26	123.19	167.30	217.00	276.45	343.35	417.00	499.16
20.....	37.05	63.23	96.67	137.63	186.02	242.33	307.33	379.56	460.30	551.79
22.....	41.28	70.63	107.60	152.49	205.28	267.56	337.58	416.42	505.63	600.42
24.....	45.91	77.70	118.86	167.60	225.72	292.07	368.72	454.26	549.40	655.19

Note.—For corresponding curves see Fig. 23, page 69.

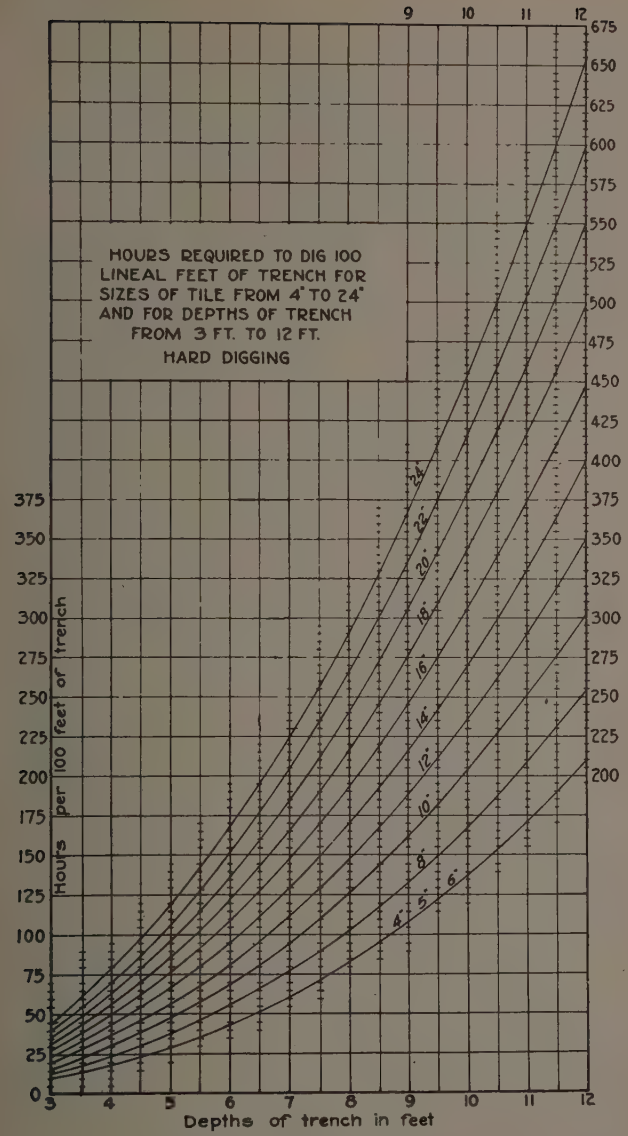


Fig. 23. Curves Showing Data in Table XXIII

TABLE XXIV

COST IN MONEY AND IN TIME OF REFILLING TRENCHES PER HOUR UNIT, PER ACRE, AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Cost in dollars							
	Total	Per hour unit	Per acre			Per		
			Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land								
1	$ 39.36	$0.43	$0.54	$2.62	$ 3.94	$ 4.47	$1.05	$15.81
3	65.00	0.44	0.86	4.64	4.64	10.34	2.11	31.71
7	47.36	0.45	0.40	2.37	5.92	4.90	0.76	11.34
8	132.60	0.60	0.56	2.37	2.37	4.83	0.69	10.37
10	207.61	0.54	1.30	5.19	15.97	16.64	2.54	37.81
14	12.00	0.52	3.43	6.00	12.00	7.27	1.62	24.24
15	289.80	0.80	0.58	1.70	2.42	5.16	0.94	14.12
17	34.08	0.36	0.25	0.97	0.97	2.20	0.18	2.66
Totals	$ 827.81							
Averages		$0.58	$0.63	$2.35	$3.22	$6.00	$0.91	$13.61
Flat Land								
2	$ 67.50	$0.35	$0.42	$0.42	$ 0.84	$ 1.89	$0.27	$ 4.03
4	36.00	0.54	0.90	1.03	7.20	8.45	2.08	31.03
5	42.08	0.49	0.23	0.35	0.42	1.64	0.19	2.86
6	57.00	0.45	0.48	0.48	0.60	2.88	0.67	10.02
9	403.60	1.16	4.25	4.25	12.61	8.70	1.92	28.87
11	250.00	0.81	0.83	1.60	3.29	4.52	0.56	8.33
12	340.00	1.07	1.33	3.40	4.53	6.07	0.63	9.39
18	3.90	0.07	0.56	0.78	1.56	1.18	0.25	3.73
Totals	$1,200.08							
Averages		$0.80	$1.03	$1.52	$2.58	$4.87	$0.67	$10.04
Peat Land								
13	$ 196.04	$2.33	$4.90	$ 7.00	$ 7.00	$13.73	$2.69	$40.34
16	50.00	1.92	2.50	3.33	3.33	11.99	2.66	39.87
Totals	$ 246.04							
Averages		$2.24	$4.10	$5.72	$5.72	$13.34	$2.68	$40.27
Grand totals	$2,273.93							
Grand average		$0.75	$0.90	$1.92	$2.97	$5.65	$0.76	$12.19

TABLE XXIV—*Continued*

COST IN MONEY AND IN TIME OF REFILLING TRENCHES PER HOUR UNIT, PER ACRE, AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Time in hour units*						
	Total hour units	Per acre			Per		
		Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land							
1	92	1.26	6.13	9.20	10.45	2.47	36.95
3	149	1.96	10.64	10.64	23.71	4.84	72.68
7	104	0.87	5.20	13.00	10.76	1.66	24.88
8	221	0.93	3.95	3.95	8.05	1.15	17.28
10	385	2.40	9.62	29.62	30.85	4.71	70.13
14	23	6.57	11.50	23.00	13.94	3.10	46.00
15	361	0.72	2.12	3.01	6.43	1.17	17.58
17	94	0.69	2.69	2.68	6.05	0.49	7.34
Totals	1,429						
Averages		1.09	4.06	5.56	10.36	1.57	23.49
Flat Land							
2	194	1.21	1.21	2.42	5.44	0.77	11.59
4	67	1.68	1.91	1.34	15.73	3.87	57.76
5	85	0.46	0.71	0.85	3.31	0.38	5.77
6	127	1.06	1.06	1.34	6.42	1.49	22.32
9	349	3.67	3.67	10.91	7.52	1.66	24.96
11	307	1.02	1.97	4.04	5.56	0.68	10.23
12	319	1.25	3.19	4.25	5.69	0.59	8.81
18	53	7.57	10.60	21.20	16.06	3.38	50.48
Totals	1,501						
Averages		1.29	1.90	3.22	6.09	0.84	12.56
Peat Land							
13	84	2.10	3.00	3.00	5.88	1.15	17.28
16	26	1.30	1.73	1.73	6.24	1.39	20.80
Totals	110						
Averages		1.83	2.56	2.56	5.96	1.20	18.00
Grand totals	3,040						
Grand averages		1.20	2.56	3.97	7.55	1.02	16.30

* The hour unit here used is a composite unit of 1 team hour plus 1⅓ man hours.

TABLE XXV

Areas and Volumes of Trenches for Sizes of Tile and Average Depths of Trench Therefor

Farm project No.	4-, 5-, and 6-inch Tile				7-inch Tile				8-inch Tile				Grand total volume, cubic feet
	Average cut, feet	Trench			Average cut, feet	Trench			Average cut, feet	Trench			
		Linear feet	Area of cross section, square feet	Volume, cubic feet		Linear feet	Area of cross-section, square feet	Volume, cubic feet		Linear feet	Area of cross-section, square feet	Volume, cubic feet	
1	3.34	7,100	2.80	19,880	3.77	900	3.70	3,330	4.06	800	4.40	3,520	
2	2.80	30,700	2.45	75,215	...		...		...		...		
3	4.03	4,110	3.55	14,591	...		...		4.50	2,175	5.05	10,984	
4	3.31	3,635	2.80	10,178	5.05	450	5.30	2,385	5.05	175	5.80	1,015	
5	3.13	21,065	2.60	54,769	...		...		...		...		
6	3.14	17,150	2.60	44,590	...		...		2.70	1,355	2.70	3,659	
7	3.19	5,633	2.66	14,984	...		...		4.15	2,365	4.55	10,761	
8	3.31	20,813	2.80	58,276	3.55	1,190	2.45	2,916	3.90	800	4.20	3,360	
9	3.29	42,657	2.80	119,440	...		...		3.34	1,040	3.45	3,588	
10	3.64	8,904	3.10	27,602	...		...		4.52	1,200	5.05	6,060	
11	3.53	43,105	3.00	129,315	...		...		4.85	2,675	5.50	14,712	
12	2.84	47,460	2.45	116,277	3.92	160	3.90	624	4.11	1,248	4.50	5,616	
13	3.56	12,325	3.00	36,975	4.80	700	5.00	3,500	4.20	1,250	4.60	5,750	
14	3.35	1,650	2.80	4,620	...		...		...		...		
15	3.54	47,731	3.00	143,193	5.41	1,750	5.80	10,150	4.93	1,150	5.65	6,498	
16	3.41	4,170	2.90	12,093	...		...		...		...		
17	3.91	9,113	3.40	30,984	4.05	700	4.05	2,835	3.93	555	4.25	2,359	
18	3.43	3,300	2.90	9,570	...		...		...		...		
Totals	...		...	922,552	...		...	25,740	...		...	77,882	1,026,174
	9-inch Tile				10-inch Tile				12-inch Tile				
6	...		...		3.22	1,275	4.00	5,100	...		...		
7	...		...		4.10	1,270	5.30	6,731	3.00	400	4.25	1,700	
8	...		...		4.20	300	5.50	1,650	4.03	2,000	6.05	12,100	
9	...		...		3.30	760	4.10	3,116	3.60	450	5.30	2,385	
10	...		...		4.79	1,214	6.25	7,587	4.76	1,160	7.40	8,584	
11	...		...		5.39	2,900	7.50	21,750	5.55	6,000	8.80	52,800	
12	...		...		4.94	1,990	6.70	13,333	5.92	542	9.60	5,203	
15	5.19	1,300	6.60	8,580	4.74	400	6.15	2,460	4.53	2,500	6.95	17,375	
17	...		...		4.49	1,100	5.95	6,545	5.09	2,177	8.00	17,416	
Totals	...		...	8,580	...		...	68,272	...		...	117,563	194,415
Grand totals carried forward													1,220,589

TABLE XXV—*Continued*

AREAS AND VOLUMES OF TRENCHES FOR SIZES OF TILE AND AVERAGE DEPTHS OF TRENCH THEREFOR

Farm project No.	14-inch Tile				15-inch Tile				16-inch Tile				Grand total volume, cubic feet
	Average cut, feet	Trench			Average cut, feet	Trench			Average cut, feet	Trench			
		Linear feet	Area of cross section, square feet	Volume, cubic feet		Linear feet	Area of cross-section, square feet	Volume, cubic feet		Linear feet	Area of cross-section, square feet	Volume, cubic feet	
Grand totals brought forward													1,220,589
2	...		...		6.50	1,000	12.80	12,800	6.50	1,500	13.48	20,220	
5	...		...		...		...		5.20	2,100	10.32	21,672	
8	4.30	200	7.40	1,480	...		...		5.00	1,500	9.85	14,775	
9	4.70	1,500	8.20	12,300	...		...		...		...		
11	5.52	200	9.95	1,990	...		...		...		...		
12	5.21	400	9.30	3,720	5.46	500	10.35	5,175	6.03	1,080	12.30	13,284	
15	5.00	1,110	8.80	9,768	3.47	155	6.10	946	...		...		
17	...		...		...		...		7.28	1,880	15.48	29,102	
Totals	...		...	29,258	...		...	18,921	...		...	99,053	147,232
	18-inch Tile				20-inch Tile				22-inch Tile				
2	6.50	2,465	14.85	36,605	...		...		...		...		
5	5.50	2,500	12.15	30,375	...		...		...		...		
8	3.20	640	6.45	4,128	...		...		...		...		
11	6.11	330	13.75	4,537	...		...		4.34	40	10.90	436	
12	7.29	270	17.05	4,604	7.12	1,542	17.95	27,679	5.37	808	13.95	11,272	
15	5.50	35	12.15	425	...		...		...		...		
Totals	...		...	80,674	...		...	27,679	...		...	11,708	120,061
Grand totals	...		...		...		...		...		...		1,487,882

From Table V the total standard hour units of 1 team hour + 1⅓ man hours is 3,040; hence average cubic feet moved per hour unit equals $\frac{1,487,882}{3,040} = 489.4$ or practically 490.

TABLE XXVI

HOUR UNITS OF ONE TEAM HOUR PLUS ONE AND ONE-THIRD MAN HOURS REQUIRED TO FILL 100 LINEAR FEET OF TRENCH FOR SIZES OF TILE FROM 4-INCH TO 24-INCH AND FOR DEPTHS OF TRENCH FROM 3 FEET TO 12 FEET

Diam. of tile	Hours per 100 linear feet for depths of trench shown on next line									
	3-ft.	4-ft.	5-ft.	6-ft.	7-ft.	8-ft.	9-ft.	10-ft.	11-ft.	12-ft.
Inches										
4, 5, and 6.....	0.50	0.72	0.96	1.23	1.52	1.83	2.18	2.54	2.93	3.34
8.....	0.62	0.88	1.17	1.50	1.82	2.18	2.56	2.97	3.40	3.86
10.....	0.75	1.05	1.38	1.74	2.11	2.52	2.95	3.40	3.88	4.38
12.....	0.87	1.22	1.60	2.00	2.42	2.87	3.34	3.84	4.36	4.91
14.....	0.99	1.38	1.80	2.24	2.71	3.20	3.72	4.26	4.83	5.42
16.....	1.11	1.55	2.01	2.49	3.01	3.55	4.11	4.69	5.30	5.94
18.....	1.22	1.70	2.21	2.75	3.31	3.88	4.49	5.12	5.77	6.45
20.....	1.33	1.86	2.41	2.99	3.59	4.21	4.86	5.54	6.24	6.96
22.....	1.45	2.02	2.62	3.24	3.88	4.55	5.25	5.96	6.70	7.47
24.....	1.56	2.17	2.81	3.47	4.16	4.87	5.61	6.37	7.16	7.97

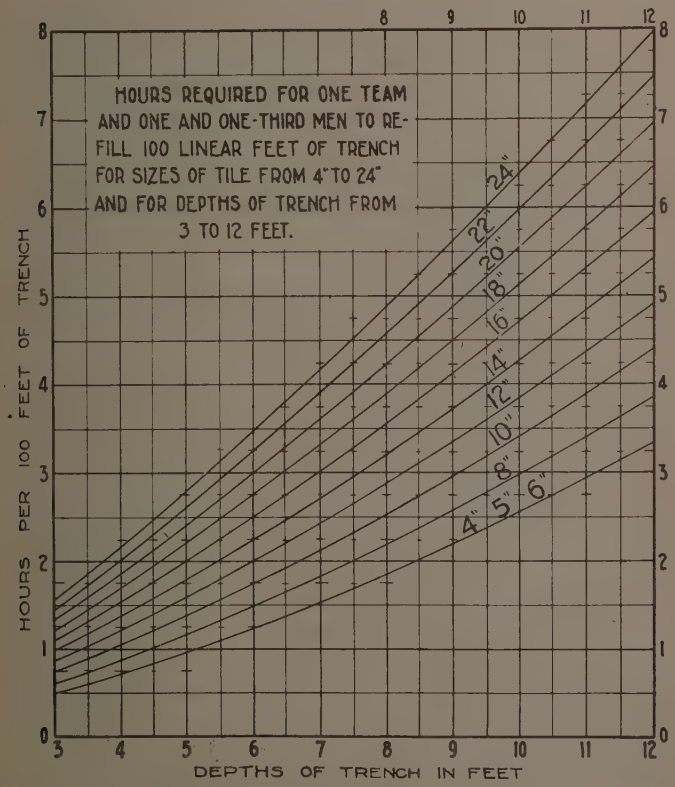


Fig. 24. Curves Showing Data in Table XXVI

TABLE XXVII

COST IN MONEY AND IN TIME, OF OUTLET PROTECTION PER MAN HOUR, PER ACRE; AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Cost in dollars							
	Total	Per hour	Per acre			Per		
			Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land								
1.....								
3.....								
7.....								
8.....	$ 21.50	$0.43	$0.09	$0.38	$ 0.38	$ 0.78	$0.11	$1.68
10.....	12.40		0.08	0.31	0.95	0.99	0.15	2.26
14.....	19.40	1.94	5.54	9.70	19.40	11.76	2.61	39.19
15.....	72.50		0.15	0.43	0.60	1.29	0.24	3.53
17.....	37.08		0.27	1.06	1.06	2.39	0.19	2.90
Totals.....	$162.88							
Averages....		$2.71	$0.12	$0.46	$0.63	$1.18	$0.18	$2.68
Flat Land								
2.....	$25.00	$0.31	$0.16	$0.16	$0.31	$0.70	$0.10	$1.49
4.....	13.06	1.30	0.33	0.37	2.61	3.07	0.75	11.26
5.....	27.75	0.40	0.15	0.23	0.28	1.08	0.13	1.88
6.....	26.00	0.58	0.22	0.22	0.27	1.31	0.31	4.57
9.....	62.03	3.10	0.65	0.65	1.94	1.34	0.30	4.44
11.....	62.50		0.21	0.40	0.82	1.13	0.14	2.08
12.....	26.00	0.58	0.10	0.26	0.35	0.46	0.05	0.72
18.....								
Totals.....	$242.34							
Averages....		$0.90	$0.21	$0.31	$0.52	$0.98	$0.14	$2.03
Peat Land								
13.....	$37.91	$3.79	$0.95	$1.35	$1.35	$2.66	$0.52	$7.80
16.....								
Totals.....	$37.91							
Averages....		$3.79	$0.63	$0.88	$0.88	$2.06	$0.41	$6.20
Grand totals..	$443.13							
Grand averages		$1.30	$0.18	$0.37	$0.58	$1.10	$0.15	$2.38

TABLE XXVII—*Continued*

COST IN MONEY AND IN TIME, OF OUTLET PROTECTION PER MAN HOUR, PER ACRE; AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Time in hours						
	Total hours	Per acre			Per		
		Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land							
1							
3							
7							
8	50	0.21	0.89	0.89	1.82	0.26	3.91
10							
14	10	2.86	5.00	10.00	6.06	1.35	20.00
15							
17							
Totals	60						
Averages		0.05	0.17	0.23	0.43	0.07	1.00
Flat Land							
2	80	0.50	0.50	1.00	2.24	0.32	4.78
4	10	0.25	0.29	2.00	2.35	0.58	8.62
5	70	0.38	0.58	0.70	2.73	0.32	4.75
6	45	0.38	0.38	0.47	2.28	0.53	7.91
9	20	0.21	0.21	0.62	0.43	0.10	1.43
11							
12	45	0.18	0.45	0.60	0.80	0.08	1.24
18							
Totals	270						
Averages		0.23	0.34	0.58	1.10	0.15	2.26
Peat Land							
13	10	0.25	0.36	0.36	0.70	0.14	2.06
16							
Totals	10						
Averages		0.16	0.23	0.23	0.54	0.11	1.64
Grand totals	340						
Grand averages		0.13	0.29	0.44	0.84	0.11	1.82

TABLE XXVIII

COST IN MONEY AND IN TIME, OF MISCELLANEOUS PER MAN HOUR, PER ACRE; AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Cost in dollars							
	Total	Per hour	Per acre			Per		
			Of watershed on farm	Drained	Reclaimed	1000 lin. ft. of tile	Ton of tile	Carload of tile
Rolling Land								
1	$17.54		$0.24	$1.17	$1.75	$1.99	$0.47	$7.04
3								
7	37.50		0.31	1.88	4.69	3.88	0.60	8.98
8	61.37	$0.31	0.26	1.10	1.10	2.24	0.32	4.80
10								
14								
15								
17								
Totals	$116.41							
Averages		$0.58	$0.09	$0.33	$0.45	$0.84	$0.13	$1.91
Flat Land								
2								
4								
5								
6								
9								
11								
12								
18								
Totals								
Averages								
Peat Land								
13	$348.00	$1.29	$8.70	$15.13	$15.13	$29.24	$6.13	$91.88
16	201.35	2.40	10.07	13.42	13.42	48.29	10.73	160.95
Totals	$549.35							
Averages		$1.55	$9.16	$12.78	$12.78	$29.78	$5.99	$89.91
Grand totals	$665.76							
Grand averages		$1.20	$0.26	$0.56	$0.87	$1.65	$0.22	$3.57

TABLE XXVIII—*Continued*

COST IN MONEY AND IN TIME, OF MISCELLANEOUS PER MAN HOUR, PER ACRE; AND PER 1000 LINEAR FEET, PER TON, AND PER CARLOAD OF TILE

Farm project No.	Time in hours: Total hours	Per acre: Of watershed on farm	Per acre: Drained	Per acre: Reclaimed	Per: 1000 lin. ft. of tile	Per: Ton of tile	Per: Carload of tile
Rolling Land							
1							
3							
7							
8	200	0.84	3.57	3.57	7.29	1.04	15.63
10							
14							
15							
17							
Totals	200						
Averages		0.15	0.57	0.78	1.45	0.22	3.29
Flat Land							
2							
4							
5							
6							
9							
11							
12							
18							
Totals							
Averages							
Peat Land							
13	270	6.75	9.64	9.64	18.91	3.70	55.55
16	84	4.20	5.60	5.60	20.14	4.47	67.20
Totals	354						
Averages		5.90	8.23	8.23	19.19	3.86	57.94
Grand totals	554						
Grand averages		0.22	0.47	0.72	1.38	0.19	2.97

TABLE XXIX

AVERAGE CUTS FROM HUB FOR GIVEN SIZES OF TILE

Farm project No.	Average cuts for sizes of tile given on next line												Average cut for all sizes over 6-in
	4-, 5-, and 6-inch	7-inch	8-inch	9-inch	10-inch	12-inch	14-inch	15-inch	16-inch	18-inch	20-inch	22-inch	
Rolling Land													
1	3.34	3.77	4.06	...	...	...	...	...	...	...	...	...	3.91
3	3.05	...	4.50	...	...	...	...	...	...	...	...	...	4.50
7	3.19	...	4.15	...	4.10	3.00	...	...	...	...	...	...	4.02
8	3.31	3.55	3.90	...	4.20	4.03	4.30	...	5.00	3.20	...	...	4.07
10	3.64	...	4.52	...	4.79	4.76	...	...	...	...	...	...	4.69
14	3.35	...	...	...	...	...	...	...	...	...	...	...	0.00
15	3.54	5.41	4.93	5.19	4.74	4.53	5.00	3.47	...	5.50	...	...	4.92
17	3.91	4.05	3.93	...	4.49	5.09	...	...	7.28	...	...	...	5.42
Averages	3.48	...	...	...	...	...	...	...	...	...	...	...	4.63
Flat Land													
2	2.80	...	...	...	...	...	...	6.50	6.50	6.50	...	...	6.50
4	3.31	5.05	5.05	...	...	...	...	...	...	...	...	...	5.05
5	3.13	...	...	...	...	...	...	...	5.20	5.50	...	...	5.36
6	3.14	...	2.70	...	3.22	...	...	...	...	...	...	...	2.97
9	3.29	...	3.34	...	3.30	3.60	4.70	...	...	...	...	...	3.89
11	3.53	...	4.85	...	5.39	5.55	5.52	...	...	6.11	...	4.34	5.37
12	2.84	3.92	4.11	...	4.94	5.92	5.21	5.46	6.03	7.29	7.12	5.37	5.55
18	3.43	...	...	...	...	...	...	...	...	...	...	...	0.00
Averages	3.14	...	...	...	...	...	...	...	...	...	...	...	5.24
Peat Land													
13	3.56	4.80	4.20	...	...	...	...	...	...	...	...	...	4.41
16	3.41	...	...	...	...	...	...	...	...	...	...	...	0.00
Averages	3.52	4.80	4.20	...	...	...	...	...	...	...	...	...	4.41
Grand averages	3.27	...	...	...	...	...	...	...	...	...	...	...	4.94

TABLE XXX

AVERAGE SIZES OF TILE AND AVERAGE RATES OF GRADE

Farm project No.	Average diameter of tile				Average grades, per cent		
	Over 6-inch		All sizes				
	Exact average	Nearest larger stock size	Exact average	Nearest larger stock size	For 6-inch tile or under	For tile over 6-inch	For all sizes of tile
Rolling Land							
1.....	7.47	8	5.19	6	1.92	2.30	1.99
3.....	8.00	8	5.73	6	0.67	0.62	0.65
7.....	9.03	9	6.69	7	0.91	0.83	0.88
8.....	12.07	12	6.94	7	0.80	0.34	0.69
10.....	9.98	10	6.50	7	1.11	1.73	1.29
14.....	0.00	..	5.00	5	1.60	0.00	1.60
15.....	10.19	12	5.89	6	0.81	0.22	0.72
17.....	11.94	12	8.09	9	0.34	0.18	0.28
Averages..	10.46	..	6.30	7	0.88	0.61	0.82
Flat Land							
2.....	16.79	18	5.96	6	0.07	0.05	0.06
4.....	7.28	8	5.05	6	0.76	0.08	0.66
5.....	17.09	18	6.48	7	0.53	0.45	0.52
6.....	8.97	9	5.05	6	0.10	0.10	0.10
9.....	11.29	12	5.09	6	0.05	0.12	0.11
11.....	10.87	12	6.42	7	0.21	0.13	0.19
12.....	14.21	14	6.48	7	0.16	0.11	0.15
18.....	0.00	..	5.00	5	0.67	0.00	0.67
Averages..	13.04	14	5.97	6	0.20	0.18	0.20
Peat Land							
13.....	7.64	8	5.39	6	0.20	0.16	0.20
16.....	0.00	..	5.00	5	0.08	0.00	0.08
Averages..	7.64	8	5.30	6	0.17	0.17	0.16
Grand averages ..	11.72	12	6.05	6	0.50	0.37	0.41

TABLE XXXI

APPROXIMATE WEIGHTS PER LINEAR FOOT OF STANDARD SIZES OF TILE

Internal diameter	Weight per linear foot to nearest pound		
	Clay or shale	Concrete	Average
Inches	Pounds	Pounds	Pounds
4	6½	7	7
5	8	10	9
6	10	13	12
7	13	16	15
8	17	23	20
9	21	25	23
10	25	30	27
12	33	43	38
14	44	59	52
15	50	65	58
16	55	83	69
18	66	102	84
20	81	124	103
22	93	154	124
24	109	190	150

TECHNICAL BULLETIN 48 JUNE 1927

University of Minnesota
Agricultural Experiment Station

Studies on the Carrion Beetles of Minnesota, Including New Species

By Melville H. Hatch
Division of Entomology and Economic Zoology

UNIVERSITY FARM, ST. PAUL

STUDIES ON THE CARRION BEETLES OF MINNESOTA, INCLUDING NEW SPECIES

By Melville H. Hatch

I. THE SILPHINAE OF MINNESOTA

The Silphinae constitute a group of about 250 species of small- to large-sized beetles, which has usually been considered of family rank. For the reasons set forth later, the author is led to reduce them to the rank of a subfamily of Staphylinidae. The student is referred to the table in the second part of the paper for a statement of the characters defining the group.

The primitive members of the Silphinae (Lyrosomini, with filiform antennae) occur for the most part on the Pacific coasts of Asia and North America and are ground inhabitants, being found under cover along streams, on beaches, and on the forest floor. They are, in all probability, predaceous in both larval and adult stages. The more highly specialized members of the subfamily (Agyrtini, Silphini, Necrodini, and Nicrophorini, with clavate antennae) represent the transition (Agyrtini) from a geobious existence to one in close relation to decaying organic matter. This is usually carrion, altho individuals occasionally wander to dung or the fruiting bodies of fungi, and there is a possibility that the last is the normal habitat of at least one species, the very rare *Necrophilus pettitii* Horn. In their new habitat, the adults continue their predaceous proclivities and feed largely upon fly-maggots. They will, however, feed on carrion if driven to it. The larvae appear to be more strictly necrophagous, and they have been raised to maturity on a purely carrion diet. The eggs are laid in the ground in close proximity to the carrion; the larvae mature and transform within a few weeks; and there seems to be but a single generation a year. Hibernation occurs in the adult stage.

The Nicrophorini, or burying bettles, are the most highly specialized tribe of the group. They have the habit of assembling in small numbers under small carcasses, and, by removing the earth underneath the carcass, gradually cause it to become buried. Thereupon the eggs are laid and the adults move on. The larvae are cylindrical eruciform insects with feeble powers of locomotion, condemned to pass their days in the midst of the food supply that their parents have provided.

There are at least three remarkable deviations from the necrobious habits of the majority of the Silphini: (1) The subgenus *Xylodrepa,* which is tree inhabiting and feeds on caterpillars; (2) the subgenera *Ablattaria* and *Phosphuga,* which feed on snails; and (3) the subgenera

Aclypea and *Blitophaga*, which are phytophagous on beets, spinach, and allied plants, and are pests of these crops in Europe and the North American Rocky Mountain region.

The Asiatic highlands have the greatest number of species of the higher tribes of Silphinae. Europe has the next largest number and North America the next. The southern regions—Australasia, Indo-Malaysia, Ethiopian Africa, and South America—have stragglers only, altho these straggling species have often come to represent peculiar types.

Selected bibliography.—For Silphinae in general, Horn. Tr. Am. Ent. Soc. VIII, 1880, pp. 219-275; Reitter, Verh. nat. Ver. Brünn XXIII, 1884, pp. 7-91; and Portevin, Ann. Soc. ent. Belg. LVIII, 1914, pp. 212-225, provide keys to the species of North America, Europe, and Japan, respectively. Keys to the smaller groups exist as follows: **Apteroloma** *(Pteroloma)* and **Lyrosoma:** Semenow, Horae Soc. Ent. Ross. XXVII, 1893, pp. 335-346; **Apatetica:** Fauvel, Rev. Ent. XIV, 1895, pp. 190-194; **Captocerus** *(Pinodytes):* Horn, Tr. Am. Ent. Soc. XIX, 1892, p. 46; **Agyrtes:** Reitter, Wien. Ent. Zeit. XX, 1901, p. 102 (Palaearctic); **Eustadia:** Portevin, Ann. Soc. ent. Belg. LVIII, 1914, p. 199; **Silphini, Necrodini, Nicrophorini:** Portevin, Ency. Ent. VI, 1926, pp. 1-270. Henriksen, Danm. Faun. Bill. V, 1922, pp. 252-260, provides keys in Danish to the larvae of some of the better known European species.

KEY TO SPECIES OF MINNESOTA SILPHINAE[1]

I. ADULTS

1 (2) Posterior coxae separate; elytra with minute strially arranged punctures at base, smooth at apex; Alaska, D.C. Tribe Catopocerini (Pinodytini) *Catopocerus cryptophagoides* Mann.

2 (1) Posterior coxae contiguous; elytra tricostate or smooth

3 (20) Antennae 11-segmented, gradually clavate; elytra tricostate

4 (19) Pronotum narrowed from base to apex; prothoracic spiracles covered. Tribe **Silphini** **Silpha** L.

5 (12) Labrum broadly emarginate; antennae inserted close to eye and distant from margin of front

6 (9) Pronotum emarginate at base Subg. **Thanatophilus** Leach.

7 (8) Intervals of elytral costae flat **trituberculata** Kby.

8 (7) Intervals of elytral costae tuberculate **lapponica** Hbst.

9 (6) Pronotum not emarginate at base Subg. **Oiceoptoma** Leach

10 (11) Elytral punctation fine; pronotum unicolorous *inaequalis* Fab.

11 (10) Elytral punctation coarser; pronotum black with reddish margins **noveboracensis** Forst.

12 (5) Labrum narrowly and deeply emarginate

[1] Minnesota species are shown in bold-face type; species likely to occur in the state, in italics.

13 (16) Antennae inserted close to margin of front and distant from eye; intervals of elytral costae smooth.....Subg. *Blitophaga* Reit.
14 (15) Form elongate oval; surface pubescent; Palaearctic, Man., Cal., N. J., Colo.*opaca* L.
15 (14) Form oblong oval; surface sparsely pubescent; Alb. and Man. to Neb., Colo. and Ore.*bituberosa* Lec.
16 (13) Antennae inserted close to eye and distant from margin of front; intervals of elytral costae reticulate
17 (18) Oblong oval; pronotum unicolorous. Subg. **Heterosilpha** Port. **ramosa** Say.
18 (17) Broadly oval; pronotum black with yellow margin. Subg. **Necrophila** Kby.**americana** L.
19 (4) Pronotum orbicular; eyes prominent; elytra usually with apical bar orange. Tribe **Necrodini**...**Necrodes (Protonecrodes) surinamensis** Fab.
20 (3) Antennae 10-segmented, capitate; elytra not evidently tricostate, in Minnesota species marked with prominent orange spots or fasciae. Tribe **Nicrophorini****Nicrophorus** Fab.
21 (22) Pronotum with orange disc.....**americanus** Ol.
22 (21) Pronotum unicolorous
23 (42) Pronotum glabrous or nearly so
24 (27) Pronotum orbicular; elytra with erect hairs
25 (26) Metatibiae straight**orbicollis** Say.
26 (25) Metatibiae curved**sayi** Lap. Cast.
27 (24) Pronotum not orbicular; elytra without erect hairs
28 (39) Metatibiae straight, at least along outer margin
29 (34) Pronotum transverse, sinuate at sides, not strongly cordate (i.e., narrowed behind), widely margined
30 (31) Antennal club black.....**defodiens** Mann.
31 (30) Antennal club with 3 apical segments orange
32 (33) Elytral margin not attaining humerus; elytra without longitudinal raised lines; Palaearctic, Alaska and Manitoba to N. Mex. and Calif., (?) Va.*investigator* Zett.
33 (32) Elytral margin nearly attaining humerus; elytra with distinct raised lines**pustulatus** Hersch.
34 (29) Pronotum cordate, strongly narrowed behind
35 (38) Metatibiae straight along both outer and inner margin; margin of pronotum wide; disc finely punctate
36 (37) Apical segment of antennal club orange.....**hybridus** H. & A.
37 (36) Antennal club entirely black.....var. **minnesotianus** nov.
38 (35) Metatibiae straight on outer margin, very feebly sinuate along inner margin; margins of prontum narrower, disc coarsely punctate; Alaska and Man. to Kan., N. Mex. and Calif.*guttulus* Mots.
39 (30) Metatibiae curved along both margins
40 (41) Basal segment of antennal club black.....**obscurus** Kby.
41 (40) Antennal club entirely orange.....**marginatus** Fab.
42 (23) Pronotum with yellow pubescence.....**tomentosus** Web.

II. LARVAE[2]

1 (13) Ocelli 6 on each side
2 (5) Campodeiform; hind angles of thoracic tergites not produced
3 (4) Prothorax very little narrower than mesothorax; dorsal plates without expanded side margins; side margins not paler.....**Thanatophilus**
4 (3) Prothorax somewhat narrower than mesothorax; dorsal plates with feebly expanded and paler side margins.....**Necrodes surinamensis** Fab.
5 (2) Blattiform; hind angles of thoracic tergites produced
6 (7, 12) Pronotum strongly emarginate in front; margins of dorsal plates strongly expanded, paler.....**Oiceoptoma**
7 (6, 12) Pronotum feebly emarginate in front
8 (11) Dorsal plates narrowly paler; phytophagous.....*Blitophaga*
9 (10) Dorsal plates glabrous (?).....*opaca* L.
10 (9) Dorsal plates with short hairs.....*bituberosa* Lec.
11 (8) Dorsal plates black at margin.....**Heterosilpha ramosa** Say.
12 (7, 6) Pronotum distinctly arcuate in front; margins moderately expanded, not paler.....**Necrophila americana** L.
13 (1) Ocelli 2; eruciform; abdominal tergites with four spines at base.....**Nicrophorus** Fab.

CATALOG OF SPECIES

The specimens upon which the following records are based are deposited in the entomological collections of either the Department of Entomology or the Department of Zoology of the University of Minnesota.

Silpha (Thanatophilus) trituberculata Kby.

A single specimen from Clearwater County (Lake Itasca), May 25. The habitat of this species is unknown, but it is probably carrion.

Silpha (Thanatophilus) lapponica Hbst.

Counties: Bigstone, Cass, Clearwater, Hennepin, Lesueur, Ottertail, Ramsey, Traverse, Wilkin. April 29-Sept. 19. Inhabits carrion. Taken mating on June 7.

Silpha (Oiceoptoma) inaequalis Fab.

This species occurs in Indiana and northern Michigan. It is doubtfully recorded from Manitoba, and may occur in Minnesota. If it occurs at all, it is very rarely, as Minnesota is close to the northern limits of its range.

Silpha (Oiceoptoma) noveboracensis Forst.

Counties: Cass, Clearwater, Hennepin, Lesueur, Ottertail, Ramsey, St. Louis, Wright. April 29-Aug. 28. Inhabits carrion.

Silpha (Heterosilpha) ramosa Say.

Counties: Dakota, Ottertail, Ramsey. June 1-Aug. 14.

[2] The author is indebted to Prof. E. O. Essig for larvae of *ramosa* Say, and to Prof. R. A. Cooley for larvae of *bituberosa* Lec.

Silpha (Necrophila) americana L.

Counties: Blue Earth, Chisago, Clearwater, Crow Wing, Itasca, Lesueur, Nicollet, Ramsey, Wright. June 22-Sept. 19. Inhabits carrion. All the Minnesota specimens belong to the abberation **affinis** Kby., in which the apex of the elytra is distinctly tipped with yellow.

Necrodes (Paranecrodes) surinamensis Fab.

Counties: Clearwater, Hennepin, Lake, Lesueur, Ramsey, Traverse, Washington. June 27-Aug. 30. Inhabits carrion. Taken in light traps in June.

A single specimen from Hennepin County belongs to the ab. **bizonatus** Port., in which there is evidence of a basal elytral fascia. Variations occur nearly all the way from individuals with an anterior fascia composed of three spots and a posterior fascia of four spots to completely immaculate forms.

Nicrophorus orbicollis Say.

Counties: Blue Earth, Chisago, Clearwater, Grant, Hennepin, Lesueur, Nicollet, Pine, Ramsey, Stearns, Traverse. May 24-Sept. 10.

Nicrophorus sayi Lap. Cast.

Counties: Nicollet, Ottertail, Pine, Ramsey, St. Louis—a single specimen from each. July 10-Aug. 28.

Nicrophorus americanus Ol.

Counties: Hennepin, Lesueur, Ramsey, Rice. May 10-Sept. 15. Apparently confined to the southern part of the state.

Nicrophorus defodiens Mann.

Ab. **humeralis** Hatch: humeral end of hypomera orange; elytral fasciae not united on disc. Counties: Clearwater, Lesueur, Hennepin. July 30-Aug. 30.

Type: humeral end of hypomera black; posterior elytral spot large, not constricted; fasciae not united on disc; anterior fascia not interrupted by suture.

Nicrophorus pustulatus Hersch.

Counties: Rice, Pine. Three specimens, June 19-Aug. 24. Taken at light on earlier date.

Nicrophorus hybridus Hatch and Angel

Counties: Itasca, Traverse, Wilkin. Five specimens.

Nicrophorus hybridus var. **minnesotianus** nov.

Type: a single specimen labeled "37" from Ramsey County.

Nicrophorus obscurus Kby.

Counties: Hennepin, Ramsey. Nine specimens.

Nicrophorus marginatus Fab.

Counties: Lesueur, Nicollet, Ramsey. May 31-Sept 6.

Nicrophorus tomentosus Web.

Counties: Bigstone, Hennepin, Lesueur, Nicollet, Norman, Ottertail, Ramsey, Traverse. July 9-Sept. 19.

II. AN INQUIRY INTO THE POSITION OF THE SILPHINAE IN THE STAPHYLINOID SERIES

The difficulty of distinguishing between the Silphinae and the Staphylinidae has gradually become apparent since the revision of the latter by Horn in 1880. Leconte and Horn in 1883, for instance, stated that the abdomen in Staphylinidae is entirely corneous above, and it was apparently on this basis that Sharp first (Ann. Mag. Nat. Hist. (6) III, 1889, p. 467), and then Fauvel (Rev. Ent. XIV, 1895, pp. 180-194) removed *Apatetica* from Silphidae. Fauvel and Ganglbauer (Käf. Mitteleur. III, 1899, pp. 1, 67-68) both pointed out that, in certain genera, which they supposed were restricted to those with a pair of ocelli (Omaliini), the two basal tergites of the abdomen were membranous, whereas Silphidae have at least the three basal segments membranous.

The outstanding characteristic of ordinary Staphylinidae is their abbreviated elytra, but exceptions in the Omaliini (characterized by the possession of a pair of ocelli) have always been recognized. An omaliin such as *Lathrimaeum nigropiceum* Csy. has long truncated elytra that expose no more than the last two abdominal tergites. Lewis (Ann. Mag. Nat. Hist. (6) XI, 1893, pp. 394-395) described *Camioleum loripes* from Japan as an omaliin with entire (non-truncate) elytra; Casey (Ann. N. Y. Acad. Sci. IX, 1897, p. 354) indicated that *Brathinus* (formerly considered a scydmaenid) was another omaliin with entire elytra; and Bondroit (Ann. Soc. ent. Belg. LV, 1911, pp. 365-369) claimed that *Pteroloma forstroemi* Gyll., likewise with a pair of ocelli and entire elytra, should be transferred from Silphidae to Staphylinidae.

But Leng (1920) made of *Brathinus* a separate family; Bondroit's claim has been ignored; Fowler (Faun. Brit. Ind. Coleop.-Introd. 1912, p. 84) considered both *Camioleum* and *Apatetica* Silphidae; and Bernet Kempers (Ent. Mitt. XIII, 1924, p. 50) considered *Apatetica* distinctly silphid on the basis of wing venation.

The contention in this paper is that neither the texture of the abdominal tergites nor the abbreviated elytra is of any value in the definition of the Staphylinidae.

As regards the first: (1) such non-omaliin Staphylinidae as *Megarthrus, Proteinus,* and *Siagonum* have the two basal abdominal tergites membranous; (2) some of the species of the omaliin genus *Lathrimaeum* have considerable portions of the basal two tergites chitinous; (3) in such an indubitable silphid as *Silpha (Oiceoptoma) noveboracensis* Forst. all the tergites are chitinous, tho the basal ones are feebly so; and (4) in the silphid *Necrophilus subterraneus* Dahl. all but the basal tergite are very evidently corneous, and very evidently different from the basal tergite, which is membranous. Therefore it

is concluded that the structure of the abdominal tergites is a variable adaptive structure of little significance.

The primitive beetle probably resembled the cockroach and some of the lampyroid families in having long, illy-adapted elytra, and similar corneous abdominal tergites. From such a beginning there was a tendency for tergites exposed by the elytra to become more heavily chitinized and for those covered by the elytra to become increasingly less heavily chitinized and, finally, membranous. Examples of beetles without any differentiation of the tergites are some of the lampyroid beetles and *Apatetica.* Even in the typical staphylinid *(Staphylinus* and *Creophilus)* there is some slight differentiation of the tergites covered by the elytra. Examples of beetles with the basal tergites differentiated but corneous, are Histeridae and Nitidulidae with the tergites heavily corneous, and *Scydmaenus* (Scydmaenidae) and *Silpha noveboracensis* Forst. (Silphinae) with the basal tergites evidently, but feebly, chitinized. The character is evanescent, and the transition to the completely membranous basal tergites is gradual.

The variation within the Omaliinae is fatal to the short elytra. Exceptions can be tolerated when they have to do with specialized features at the tips of the phylogenetic "twigs." When, however, the primitive members of a group constitute the exceptions, the group is inadequately defined.

This leaves us, therefore, with no characters separating Silphinae and Leptininae from Staphylinidae, and they become subfamilies of Staphylinidae. The very feature, closed anterior coxal cavities, that distinguishes the other subfamilies of "Silphidae" from Silphinae, distinguishes them, likewise, from Staphylinidae, and I, therefore, group the Catopinae, Coloninae, Camiarinae, and Bathysciinae together to form a separate family, Catopidae. These matters and others are set forth in the following table,[3] in which an attempt has been made to arrange the groups in a natural sequence.

A¹. Wings not fringed
 B¹. Antennae not both geniculate and clavate
 C¹. Procoxacavae not invading metathorax
 D¹. Facets of eye normally small
 E¹. Abdominal segments not at all connate
 F¹. Procoxacavae open behind.....**STAPHYLINIDAE**
 G¹. Metacoxae contiguous or narrowly separated
 H¹. Metacoxae conical; **elytra abbreviated;** procoxae prominent

[3] Derivative characters are printed in bold-face type and intermediate characters in italics. In the Staphylinidae the subfamilies Trichophyinae, Termitidiscinae, Cephaloplectinae, Pygostenínae, Trilobitideinae, and Mimanomatinae of the Junk-Schenkling catalog are not included. For an artificial key to the subfamilies of Staphylinidae see Handlirsch, Schroder's Handb. d. Ent. III, 1923, pp. 567-569. The key to subfamilies of Catopidae is adapted from Jeannel, Arch. Zool. exp. gen. (5) VII, 1911, pp. 192-193; LXI, 1922, pp. 8-9.

I¹. Tarsi 5-segmented **(rarely with middle and hind pair 4-segmented)**; procoxae long....**Paederinae**
I². **Tarsi 4-segmented**; *procoxae short*..**Euaesthetinae**
H². *Metacoxae triangular;* **elytra abbreviated**; procoxae prominent
I¹. Antennae normal, inserted at sides of front....**Habrocerinae**
I². **Antennae inserted at front of front**...**Staphylininae**
H³. *Metacoxae transverse*
I¹. Procoxae prominent, conical
J¹. Lateral ocelli present; elytra long to short; sternites 7 to 5; middle coxae contiguous..**Omaliinae**
J². **Lateral ocelli absent**
K¹. Elytra long; *sternites 6 to 5;* mesocoxae contiguous **to separate**.....**Silphinae**
K². **Elytra abbreviated**
L¹. Sternites 7
M¹. Mesocoxae contiguous **Oxytelinae**[4] (Megalopinae)
M². **Mesocoxae separated****Oxyporinae**
L². *Sternites 6*
M¹. Antennae normal, inserted at sides of head
N¹. Head directed forward; body slender**Phloeocharinae**
N². **Head inclined; body broader**.. **Tachyporinae**
M². **Antennae inserted between eyes**.. **Aleocharinae**
I². *Procoxae short, conical;* **elytra abbreviated; tarsi 2-segmented** **Leptotyphlinae**
I³. **Procoxae globose**
J¹. **Without eyes or wings**; elytra entire to abbreviated **Leptininae**[5]
J². **Elytra abbreviated**; with eyes and wings.. **Piestinae**
G². **Metacoxae widely separated, small, globose; elytra abbreviated; antennae clavate**
H¹. Antennae 11-segmented, **inserted between eyes**; club loose**Steninae**
H². **Antennae 9-segmented**, inserted at sides, **capitate** **Micropeplinae**
F². **Procoxacavae closed behind**; elytra entire
G¹. Metatrochantin large**CATOPIDAE**
H¹. Metacoxae contiguous; tarsi pentamerous
I¹. Visible sternites 7 to 6; antennal club loose

[4] This subfamily includes *Phlacobium clypeatum* Muell, the only beetle, except certain Dermestidae, to possess a median ocellus.

[5] Includes *Platypsyllus:* Jeannel, Arch. Zool. exp. gen. LXI, 1922, p. 9. For keys to genera see Horn. Tr. Am. Ent. Soc. X, 1882, p. 13; Olsoufiev, Rev. Russ. Ent. XVII, 1923, p. 88.

J¹. Last segment of maxillary palpi conical or oval Catopinae
J². **Last segment of maxillary pulpi scuriform;** New Zealand Camiarinae
I². Sternites 5 to 4; antennal club more compact.. Coloninae
H². **Metacoxae somewhat separated;** visible sternites 6; ♂ **tarsi 5- to 4-segmented;** ♀ **tarsi 4-segmented** Bathysciinae
G². **Metatrochantin** small..... ANISOTOMIDAE
E². **Abdominal segments in part connate;** elytra abbreviated.. PSELAPHIDAE, CLAVIGERIDAE
D². **Facets of eye large; metacoxae widely separated;** elytra entire SCYDMAENIDAE
C². **Prothorax closely fitted to metathorax so that procoxae invade mesosternum; metacoxae widely separated**.....SCAPHIDIIDAE
B². **Antennae geniculo-clavate** SPHAERITIDAE, HISTERIDAE, NIPONIIDAE
A². **Wings fringed** CLAMBIDAE, PTILIIDAE, ORTHOPERIDAE, SPHAERIIDAE, *et al.*

The Staphylinidae constitute a great aggregate of primitive staphylinoid beetles, held together by the common possession of a series of primitive characters; and from this primitive group the remaining staphylinoid families are segregated off by the possession of one or more derivative characters. Of these the Scydmaenidae are the most unsatisfactorily segregated. The Catopidae and Anisotomidae may, perhaps, be united to form a single family, in which case the name Anisotomidae will have priority. Such a union is possibly suggested by the wing folding (Forbes, Jr. N. Y. Ent. Soc. XXXIV, 1926, pp. 67-68). There is no basis for the segregation of the superfamily Silphoidea of the Leng (1920) classification.

The subfamilies of Staphylinidae are grouped primarily on the basis of coxal characters. The primitive coleopteron undoubtedly resembled the cockroach, where the coxae are contiguous, elongate, and loosely connected with the sternum. As beetles became more specialized, the coxae became more and more intimately associated with the sternum, until they became completely embedded in it, forming the globose separated coxae of the books. Four major groups are thus indicated by the increased specialization of the metacoxae. To the third of these groups belong the Omaliinae and the Silphinae.

I have made the possession of a pair of ocelli definitive for the Omaliinae. All of the Coleoptera possessing this characteristic occur in this vicinity and I believe that little violence is done by bringing them within this subfamily. It is a very primitive characteristic and, despite the modification of the metacoxae, reveal the Omaliinae as

among the most primitive of Coleoptera. The subfamily, therefore, includes *Camiolcum*[6] and *Brathinus*, as recognized by the Junk-Schenkling catalog. *Pteroloma forstroemi* Gyll., formerly placed in Silphinae, and *Micragyrtes ocelligerus* Champion (Ent. Mo. Mag. LIV, 1918, p. 46) from Chili, regarded by its describer as belonging to Silphinae. *Pteroloma forstroemi* Gyll. is characterized by six visible abdominal sternites, elytra entire with nine entire striae, antennae filiform, and all but the basal one or two abdominal tergites evidently chitinized. *Micragyrtes* is described as having five sternites, elytra confusedly punctate, truncate at apex, segments 8-11 of antenna forming a compact club.

The removal of *Pteroloma forstroemi* Gyll. from the Silphinae requires that the first tribe of that subfamily take the name of Lyrosomini, Horn, 1880. The remaining species of *"Pteroloma,"* without ocelli, may be placed in **Apteroloma** gen. nov. (type *Necrophilus tenuicornc* Leconte, 1859). Finally, I see no good reason for not restoring *Apatetica* and *Nodynus* to Silphinae. *Apatetica* can not remain in Piestinae, as placed by Fauvel, because its anterior coxae are transverse and not globose. This and other genera, however, stand near the parting of the ways.

The author has attempted in the following table[7] to show to what extent larval structures corroborate adult structures in the classification of the Staphylinoidea.

A¹. Cerci usually multi-segmented.....**CATOPIDAE, ANISOTOMIDAE**
A². Cerci bisegmented (unsegmented in some Staphylinidae)
B¹. Eyes present.....**STAPHYLINIDAE**
C¹. Labrum present**Silphinae**
C². Labrum absent**other Staphylinidae**
B². Eyes absent**HISTERIDAE**
A³. Cerci unsegmented
B¹. Cerci stout**PSELAPHIDAE(?), PTILIIDAE, PLATYPSYLLIDAE, SCAPHIDIIDAE**
B². Cerci hairlike**CLAMBIDAE**
A⁴. Cerci absent.....**CORYLOPHIDAE, SCYDMAENIDAE**

In my view there is here exhibited a progressive degeneration of the cerci. It is not impossible, however, that the multi-segmented condition of the cerci of Catopoidae and Anisotomidae is the result of the secondary annulation of the second segment of a bisegmented cercus.

[6] By a curious oversight this genus is listed twice in Winkler's Cat. Col. reg. Palaear.—in Silphidae (B843) and in Staphylinidae (B3190).

[7] Compiled largely from Ganglbauer (Käf. Mitteleur. III, 1899) and Kuhnt (Ill. Best. Tab. Käf. Deut. 1913, p. 1079-1085).

III. NOTES ON CATOPIDAE AND ANISOTOMIDAE

Catopidae

The Catopidae are a group of about 625 small, obscure, fragile, rapidly running beetles, bearing little or no superficial resemblance to the Silphinae. They seem, primitively, to have been geobious (living under stones, leaves, roots of grass, moss, etc.: *Choleva, Nargus, Colon,* some Bathysciinae) and to have branched out from this to the occupancy of a number of other situations. Different members of the family have come to occupy one or another of the following habitats: (1) decaying vegetable matter *(Catops, Choleva, Ptomaphagus);* (2) fungi *(Sciodrepa, Catops);* (3) carrion *(Ptomaphagus, Catops, Prionochaeta);* (4) ant nests *(Nemadus, Synaulus, Adelops, Attumbra, Catopsimorphus);* (5) dens of animals *(Catopidius,* some *Catops);* (6) caves *(Anemadus* subg. *Speonemadus,* Bathysciinae, and scattered species of *Dissochactus, Ptomaphagus, Choleva, Adelops,* etc.). Specimens of *Colon* are rarely taken, and then, usually, flying or sweeping vegetation, which they climb under proper meteorological conditions in order to take flight.

Of great biological interest are the Bathysciinae, of which over 80 genera and about 270 species and 160 subspecies and varieties are recognized in Europe by Jeannel. The great majority of these are blind, inhabiting the caves of southern Europe, where Jeannel believes they arose in the Balkan Peninsula. In many cases the caves seem to have had an isolating effect similar to oceanic islands, and numerous peculiar forms have arisen in consequence. In some of the species the abdomen has become greatly enlarged and globose, paralleling, perhaps, the eccentricities of growth that are not infrequent in many myrmecophiles and termitophiles, likewise dwellers in dark places. *Platycholeus leptinoides* Horn is the only Nearctic representative of the subfamily.

The subfamilies of Catopidae are included in the key to the Staphylinoid families. Of these the Bathysciinae have been mentioned, the Camiarinae are little understood, and the Coloninae include but a single genus. The Catopinae have recently been studied by Jeannel (Arch. Zool. exp. gen. LXI, 1922, pp. 12-52). An extensive classification and phylogenetic scheme is there devised, based in important measure on the male genital tube. The following key to adults based on external characters is adapted from that work and from Jeannel, Voyage Alluaud Jeannel Afr. orient. Col. XVI, 1922, p. 235. The key to the larvae of Catopidae and Anisotomidae is taken from Ganglbauer, Käf. Mitteleur. III, 1899, pp. 208, 235, 240, and Peyerimhoff, Ann. Soc. ent. Fr. LXXVI, 1907, p. 87.

KEY TO GENERA OF CATOPINAE[8]

1 (6) Maxillary palpi filiform, 2d segment narrow, 3d segment cylindrical, elongate, longer than 2d and not much narrower; oriental, Ethiopian, neotropical *Eucatopini*

2 (3) Protarsi not flattened; ♂ protarsomeres not dilated; East Africa.... *Oritocatops* Port.

3 (2) Protarsi flattened; ♂ protarsomeres dilated

4 (5) Elytra transversely striolate; neotropical..... *Eucatops* Port.

5 (4) Elytra not transversely striolate; neotropical..... *Sphacrocatops* Port.

6 (1) Maxillary palpi with 2d segment oval, 3d small, conical, narrower and shorter than 2d..... **Catopini**

7 (17) Elytra transversely striolate; mesosternum carinate (except in *Dissochaetus*)

8 (12) Protibia not enlarged at apex; tibiae with 4 spines at apex.... **Anemadina**

9 (10, 11) Two basal mesotarsomeres expanded in ♂; mesosternal carina low; Mediterranean *Anemadus* Reitt.

10 (9, 11) Basal mesotarsomere expanded in ♂; mesoternal carina elevated; myrmecophilous; palaearctic..... *Nemadus* Reitt

11 (9, 10) Mesotarsomeres not expanded in ♂; mesosternal carina low; neotropical, Florida **Dissochaetus** Reitt.

12 (8) Protibia enlarged at apex; tibiae with fringe of spinules at apex; mesotarsomeres not expanded in ♂ **Ptomaphagina**

12 (16) Pronotum transversely striolate

14 (15) Antennae normal; palaearctic, nearctic, neotropical..... **Ptomaphagus** Ill.

15 (14) Antennae short with broad oval club; myrmecophilous; North Africa *Synaulus* Port.

16 (13) Pronotum not transversely striolate; cavernicolous and myrmecophilous; nearctic **Adelops** Tellk.

17 (7) Elytra not transversely striolate (except *Catops decipiens* Horn); mesosternum not carinate

18 (25) Apex of protibia with 4 spines; mesotarsomeres not dilated in ♂; palaearctic *Cholevina*

19 (24) Form short, convex

20 (23) Antennae normal

21 (22) Antennae without long hairs; Mediterranean..... *Nargus* Thoms.

22 (21) Antennae with long hairs; myrmecophilous; Mediterranean, Caucasus *Attumbra* Goz.

23 (20) Antennae short with solid, broad, oval club; myrmecophilous; Mediterranean to India..... *Catopsimorphus* Aubé.

24 (19) Form elongate; flattened; palaearctic..... *Choleva* Latr.

25 (18) Apex of tibiae with fringe of spinules..... **Catopina**

26 (41) Basal mesotarsomere enlarged in ♂

27 (30) Pronotum wide, little narrower than elytra

28 (37) Form less elongate

29 (36) Sides of pronotum not sinuate

30 (33) Sides of pronotum recurved at base

31 (32) 8th segment of antenna narrower than 7th and 9th; palaearctic, nearctic **Catops** Payk.

32 (31) 8th segment of antenna as wide as 7th and 9th; nearctic..... **Echinocolus Horn**

[8] Nearctic groups in bold-face type. Numerous genera from the southern hemisphere are not included.

33 (30) Sides of pronotum not recurved at base
34 (35) Antennal club broader, 6th segment transverse; palaearctic, nearctic **Sciodrepa** Thoms.[9]
35 (34) Antennal club feeble, 6th segment as long as wide; myrmecophilous; Europe *Dreposcia* Jeann.
36 (29) Sides of pronotum sinuate; pholeophilous; France.... *Catopidius* Jeann.
37 (28) Form more elongate
38 (39) Antennae longer with conical club; Mediterranean, transcaspian territory *Cholevinus* Reitt.
39 (38) Antennae flabellate; Alaska to British Columbia.... **Catopotrichus** Murr.
40 (27) Pronotum narrow, convex; elytra wide; Alps..... *Chionocatops* Ganglb.
41 (26) Basal mesotarsomere not enlarged in ♂
42 (33) Pronotum as wide as elytra; Siberia, Japan, nearctic.. **Prionochaeta** Horn
43 (42) Pronotum narrower than elytra; Carpathians, Himalayas..... *Rybinskiella* Reitt.

KEY TO LARVAE OF CATOPIDAE AND ANISOTOMIDAE[10]

1 (12) Mandibular tooth transversely wrinkled or with transversely arranged denticles; paraglossae absent..... **CATOPIDAE**
2 (9) Antennae inserted in line with greatest transverse diameter of head; apex of mandible narrow and acute..... **Catopinae**
3 (4) Galea filiform; ligula absent; mandible without spine but with an acute dentiform appendage; eyes pigmented..... **Catops, Sciodrepa**(?), **Ptomaphagus**
4 (3) Galea comb-like; ligula long; eyes not pigmented
4a (4b) Antennae evidently longer than head; mandibles regularly tridentate at apex; bristles broad..... *Anemadus*
4b (4a) Antennae shorter, scarcely longer than head; mandibles irregularly bifid or trifid
5 (6) Labial palpiger distinct; first segment of maxillary palpus shorter than second; dorsal bristles broad..... **Adelops**
6 (5) Labial palpiger indistinct; first segment of maxillary palpus longer than second
7 (8) Body elongate, covered with simple elongate bristles; 2d segment of antenna longer than first; mola of mandible distinct; cerci very long; metacoxae contiguous *Catopsimorphus*
8 (7) Body short, covered with short broad bristles; antennae small; mola with feebly visible ridges; cerci short; all the coxae separated..... *Synaulus*
9 (2) Antennae inserted along the front opposite the outer margin of the mandible, the apex of which is broad; bristles broad; galea comb-like; ligula long; eyes not pigmented..... *Bathysciinae*
10 (11) Mandible without spine or dentiform appendage; mola with numerous (15) ridges; maxillae elongate; 2d segment of cerci not annulated.. *Aphaobius*
11 (10) Mandible with a spine or dentiform appendage; mola with fewer (8 to 10) ridges; maxillae less elongate; 2d segment of cercus annulated *Bathyscia*

[9] In the author's opinion the nearctic *Catops terminans* Lec. is a synonym of *Sciodrepa fumatus* Spence, extending the range of both genus and species to the nearctic region.

[10] Nearctic groups in bold-face type.

12 (1) Mandibular tooth covered with confused tubercles; paraglossae distinct **ANISOTOMIDAE**
13 (16) Head half as wide as pronotum; body narrowed behind; with ocelli
14 (15) Abdominal tergites covering pleura and stigmata; chitinous plates with short bristles; 2d segment of antenna 1½ times the length of 1st **Anisotoma**
14 (14) Abdominal tergites not covering pleura and stigmata; chitinous plates with long bristles; 2d segment of antenna twice the length of 1st... **Agathidium**
16 (13) Head nearly as wide as pronotum; body parallel; ocelli absent..... **Liodes**

Selected bibliography for Catopidae.—General references the same as for Silphinae, but also see Ganglbauer, Käf. Mitteleur. III, 1899, pp. 75-155, and Kuhnt, Ill. Best.-Tab. Käf. Deut. 1913, pp. 324-334, for European species. Keys to the species of the subdivisions exist as follows: **Anemadus** subg. *Speonemadus:* Jeannel, Arch. Zool. exp. gen. LXI, 1922, pp. 56-58; **Ptomaphagus:** Seidlitz, Deut. Ent. Zeit. XXI, 1887, pp. 90-93 (Palaearctic); **Nargus:** Reitter, Wien. Ent. Zeit. XXV, 1906, p. 141; **Choleva:** Jeannel, L'Abeille XXXII, 1923, pp. 1-160 (Palaearctic); **Catopsimorphus** subg. *Attaephilus:* Reitter, Deut. Ent. Zeit. XXII, 1888, p. 422; **Attumbra:** Reitter, Deut. Ent. Zeit. XXIII, 1889, p. 372; **Catops** to **Chionocatops:** Reitter, Deut. Ent. Zeit. 1901, pp. 39-48 (Palaearctic); **Rybinskiella:** Reitter, Deut. Ent. Zeit. 1913, p. 667; **Bathysciinae:** Jeannel, Arch. Zool. exp. gen. LXIII, 1924, pp. 1-436.

Only two species of Catopidae have so far been taken in Minnesota, altho ten or twelve should occur according to the distribution given in the Leng Catalog.

Adelops brachyderus Lec.

This species, placed in *Ptomaphagus* by Horn and Leng, is represented by a series of over thirty specimens from Ramsey and Hennepin Counties in the Lugger collection. It is recorded from the nest of the ant, *Camponotus pictus*, by Schwarz, Proc. Ent. Soc. Wash. I, 1889, p. 170.

Catops horniana Blanchard

This species, placed in *Choleva* in the Leng Catalog, is represented by three specimens taken on carrion in Ramsey and Anoka Counties, May and June, 1927.

ANISOTOMIDAE[11]

The members of this family are small, obscure species rarely encountered by the general collector. They inhabit decaying vegetable matter, fungi, and the subcortical region of dead trees.

[11] Liodidae of current European literature. *Liodes* Latreille, 1796, even tho it antedates *Anisotoma* Illiger 1798, can not serve as the type of the family, since it did not serve as the type of a supergeneric group until Liodini Reitter 1884, whereas *Anisotoma* served as the type of Anisotomidae Stephens 1829.

Selected bibliography for Anisotomidae.—Horn, Tr. Am. Ent. Soc. VIII, 1880, pp. 275-308; Reitter, Verh. nat. Ver. Brünn XXIII, 1884 (Best.-Tab. eur. Col. XII), pp. 91-122; Portevin, Ency. Ent. B. Col. I, 1926, pp. 75-83, and II, 1927, pp. 73-94, provide keys to the species of North America, Europe, India, and Japan, respectively. For the **Liodini** of Europe see Fleischer, Verh. nat. Ver. Brünn XLVI, 1908 (Best.-Tab eur Col. LXIII), p. 1-63. For **Scotocryptini** see Reitter, *ibid.*, pp. 91-92, and Portevin, Ann. Soc. ent. Fr. LXXVI, 1907, p. 84. Many of these works are old and the descriptions must be checked carefully against the descriptions of the more recently discovered species.

Tho ten or twelve species should occur in Minnesota according to the distribution given in the Leng Catalog, only a single species of Anisotomidae is represented in the collections of the University of Minnesota, and that a new species of a genus formerly known only by two species from Florida.

Anogdus luggeri n. sp.

With antennal and tarsal characters of genus. Length 2 mm., width 1.25 mm. Color straw yellow, somewhat darker on antennae, vertex, base of pronotum, marginal beads of pronotum and elytra, and abdomen. Head finely and uniformly punctulate. First segment of antennal club about 4/5 as wide as 2d and 3d, wider than 4th. Pronotum 56% as long as wide, apex 61% as wide as base, feebly emarginate at apex, arcuate at base, but slightly sinuate immediately mesad of the hind angles which are obtuse but distinct, sides arcuate, sides and apex very finely margined, disc finely punctulate. Elytra with eight finely punctate striae, not or feebly impressed. Intervals finely punctulate. Margin with short stiff yellow hairs. Legs with coarse stiff yellow hairs.

Type: "Minn." from Otto Lugger collection in the University of Minnesota insect collection.

Key to species of Anogdus Lec.

A¹. Pronotum less than twice as wide as long, disc finely punctate, base arcuate; elytral striae finely punctate

B¹. Hind angles of pronotum distinct; 7th segment of antenna nearly as wide as 8th and 9th, wider than 10th; pronotum 56% as long as wide; length 2 mm.; Minn. **luggeri** n. sp.

B². Hind angles of pronotum rounded; 7th segment of antenna not much more than half as wide as 8th and 9th, same width as 10th; length 2.2-2.4 mm.; Fla. *dissimilis* Blatch.

A². Pronotum three times as wide as long, disc coarsely punctate, base truncate, hind angles rounded; elytral striae crenately punctate; 7th segment of antenna as wide as 8th and 9th, wider than 10th; length 2.5 mm.; Fla. *capitatus* Lec.

This opportunity is taken to describe a second new anisotomid in the Lugger collection, apparently from Alaska.

Hydnobius luggeri n. sp. ♂ Length 2.5 mm.; width through pronotum 0.9 mm., through elytra 1.3 mm. Throughout reddish brown, shining. Labrum bilobed. Head and pronotum sparsely punctate, the punctures finer than those on elytra. Third segment of antenna shorter than next two. Pronotum 77% as long as wide at base, 88% as wide at apex as at base, anterior angles rounded, posterior angles feebly prominent, obtuse; sides arcuate, just visibly wider in front of base; base and apex arcuate. Elytra with about 18 rows of punctures, the second or sutural and the 18th or marginal impressed, the sutural not impressed for basal fifth; the punctures of the 15th and 17th rows somewhat smaller; the intervals of the rows of punctures not strigose or wrinkled. Four basal segments of pro- and mesotarsi dilated. Profemur oblong, 30% as wide as long, inner margin simple. Metafemur broad, arcuate along inner margin. Metatibia straight.

Type: "R.A." in Otto Lugger collection, University of Minnesota.

This species, undoubtedly from Alaska, runs to *obtusus* in Horn's key, but it is separated from that species by its slenderer profemur, the inner margin of which is not broadly lobed, and by the extensive development of the interstrial puncture-series, so that there appear to be 18 nearly equal rows of punctures on each elytron.

The distribution of the Minnesota species mentioned in this paper is summarized in the accompanying table. The number of species is not extensive enough to warrant distributional conclusions.

	Palaearctic	Alas., N.W. Ter.	Pacific	Rocky Mts.	N. Gt. Plains	Minn.	Wis., Ont., Mich.	Neb., Kan., Ind.	N.E. N. Am.	S.E. N. Am.	Gulf St.	S.W. St.	Neotropical
Silpha trituberculata...		x			x	x	x						
lapponica	x	x	x	x	x	x	x	x	x			x	x
noveboracensis				x	x	x	x	x	x	x			
ramosa			x	x	x	x	x						
americana					x	x	x	x	x	x	x	x	x
Necrodes surinamensis...				x	x	x	x	x	x	x	x	x	?
Nicrophorus orbicollis..					x	x	x	x	x	x	x		
sayi				x	x	x	x	x	x	x	x		
americanus						x	x	x	x	x	x		
defodiens		x	x	x	x	x	x		x				
pustulatus	x	x	?	x	x	x	x	x	x	x	x		
hybridus			x	x	x	x			?			?	
obscurus				x	x	x	x						
marginatus		x	x	x	x	x	x	x	x	x	x	x	x
tomentosus			x	x	x	x	x	x	x	x	x	x	
Catops horniana.....					x	x		x					
Adelops brachyderus....						x	x		x				
Anogdus luggeri						x							

University of Minnesota
Agricultural Experiment Station

A Comparison of the Toxicity and the Diffusion in a Column of Grain, of Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride

A. L. Strand
Division of Entomology and Economic Zoology

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	3
Acknowledgment	3
Toxicity to insects of chlorpicrin, carbon disulphide, and carbon tetrachloride	4
Experiments conducted as a means of determining the relative toxicity of carbon tetrachloride, carbon disulphide, and chlorpicrin at different temperatures	7
Diffusion of chlorpicrin, carbon disulphide, and carbon tetrachloride in grain	13
Historical summary	13
Method used for estimating diffusion of chlorpicrin, carbon disulphide, and carbon tetrachloride	15
Experiments on the diffusion of chlorpicrin and carbon disulphide in a column of grain	17
Conclusions	29
Literature cited	30
Appendix	32
Results of experiments with chlorpicrin	32
Results of experiments on adsorption	45

ILLUSTRATIONS

		Page
Fig.	1. Diagram of fumigation chamber	8
	2. Time and temperature curves for toxicity	12
	Time and concentration curves for toxicity	12
	4. Diagram of apparatus in which tubes of charcoal were exposed to known concentrations of chlorpicrin, carbon disulphide and carbon tetrachloride under constant temperature and humidity conditions	16
	5. Adsorption isotherms for chlorpicrin	17
	6. Adsorption isotherms for chlorpicrin	18
	7. Adsorption isotherms for carbon disulphide	18
	8. Adsorption isotherms for carbon disulphide	18
	9. Adsorption isotherms for carbon tetrachloride	19
	10. Adsorption isotherms for carbon tetrachloride	19
	11. Diagram of fumigation chamber	20
	12. Relation of temperature to adsorption on active charcoal	28

A COMPARISON OF THE TOXICITY TO INSECTS AND THE DIFFUSION IN A COLUMN OF GRAIN, OF CHLORPICRIN, CARBON DISULPHIDE, AND CARBON TETRACHLORIDE

By A. L. Strand

INTRODUCTION

For fifty or more years carbon disulphide has been used as a fumigant against a wide variety of insect pests. The early work was concerned mainly with showing its toxicity, but the more recent work has dealt with the effects of temperature, leakage, and other factors in connection with its use. Likewise, it has been well established that carbon tetrachloride, altho possessing the important advantage of being non-inflammable, is a much weaker fumigant than the disulphide. Within the last ten years the high toxicity of chlorpicrin to insects has been thoroly demonstrated. This fact and the knowledge that it is non-inflammable have led workers in many different countries to look upon chlorpicrin as one of the most promising substances in the field of insect fumigation. These three materials have been compared, but they have not been compared under controlled conditions over a range of temperatures.

Because of the irritating effects of chlorpicrin on man, and owing to certain of its physical properties, the practical use of chlorpicrin as a fumigant has centered on the technic for its application. As one of its chief uses is the treatment of infested grain, more accurate knowledge was desired concerning its diffusion in grain. It was thought that the manner of its diffusion would be the initial step in arriving at the most intelligent method of application. Furthermore, as chlorpicrin, when used as a fumigant on stored products, is necessarily compared with the better-known carbon disulphide and carbon tetrachloride, it was believed that the diffusion of these chemicals in grain should be studied at the same time. Consequently the purpose of this present work has been two-fold (1) to determine the relative toxicity of carbon tetrachloride, carbon disulphide, and chlorpicrin to insects at various temperatures; and (2) to study the manner of diffusion of these chemicals when applied to threshed grain in storage. The two divisions of the work will be taken up in that order.

Acknowledgment

The writer wishes to acknowledge the helpful suggestions of Dr. R. N. Chapman, as to both the initiation of the problem and it development.

TOXICITY TO INSECTS OF CHLORPICRIN, CARBON DISULPHIDE, AND CARBON TETRACHLORIDE

Historical Summary

Piutti and Bernardini (1917)[1] and Moore (1917) were the first to point out the high toxicity of chlorpicrin to insects. Moore rated it above carbon tetrachloride and carbon disulphide. In millionths of gram molecules necessary to kill house flies in 400 minutes, the three compared as follows: chlorpicrin, 1.7; carbon tetrachloride, 161.9, and carbon disulphide, 286.3. In a later publication, Moore (1918) stated that, molecule for molecule, chlorpicrin was 283 times as toxic as carbon disulphide. In the same paper he showed that chlorpicrin at the rate of half a pound to 1000 cubic feet killed the bean weevil (*Bruchus obtectus* Say), the Angoumois grain moth (*Sitotroga cerealella* Oliv.), the Indian meal moth (*Plodia interpunctella* Hbn.), and the Mediterranean flour moth (*Ephestia kuehniella* Zell.), but did not kill the confused flour beetle (*Tribolium confusum* Duv.) deeper than an inch in the flour. For the last named insect, he stated that a concentration of 1 or 2 pounds of chlorpicrin should be used, and that to obtain similar results with carbon disulphide from 3 to 5 pounds per 1000 cubic feet at temperatures above 65° F. would be required. Moore (1918) also pointed out that chlorpicrin gave good results at temperatures below 60° F.

Bertrand, Brocq-Rousseu, and Dassonville (1919c) found that they could kill *Tribolium navale* Hbst. in 1 hour and 20 minutes at a concentration of 30 grams per cubic meter (slightly less than 2 pounds to 1000 cubic feet) at a temperature between 14° and 19° C., and that at reduced concentrations longer periods were required. They demonstrated that *T. navale* was much harder to kill than the grain weevil (*Sitophilus*) and that a separation of the two insects in a mixed infestation could be effected with chlorpicrin. These authors in another paper (1919b) have given the best account of the effect of temperature on the insecticidal power of chlorpicrin. Data given show that at 37° C. 20 grams per cubic meter killed *Sitophilus oryza* L. in 31 minutes while at 0° C. 4 hours was required.

Wille (1921a) has reviewed the work of Bertrand and his associates and in another paper (1921b) states that chlorpicrin at the rate of 30 cc. per cubic meter kills the grain weevil in 6 hours.

Bertrand and Rosenblatt (1919) showed that, out of eight chemicals used, chlorpicrin was most toxic to *Bombyx neustria* L., even more so than hydrocyanic acid gas. The insects were subjected to measured amounts of air and poisonous vapors for periods from 10 minutes to

[1] The writer has not seen this reference.

1 hour. The toxicities were ranked as follows: chlorpicrin, hydrocyanic acid, chloracteone, benzyl bromide, carbon disulphide, chloroform, carbon tetrachloride, and ether. No difference was noted in the relative toxicity of these substances toward different species of insects. Again Bertrand, Brocq-Rousseu, and Dassonville (1919a) found that the bedbug (*Cimex lectularius* L.) was killed at a concentration of 20 grams of chlorpicrin to 1 cubic meter in 33 minutes (or a minimum of 20 minutes), and that at concentrations of 1 gram per cubic meter 12 hours and 22 minutes were required. The time required to kill with intermediate amounts was proportional to the dosage.

Burchardt (1920) believed that chlorpicrin was not so good a fumigant as carbon disulphide. In fumigating sacks of grain in a granary he used 10 grams of chlorpicrin per cubic meter and failed to secure a kill in 48 hours, while with carbon disulphide good results were secured in from 6 to 24 hours. The insects concerned were *Sitophilus, Laemophlocus ferrugineus* Steph., and *Orysaephilus surinamensis* L.

Feytaud (1920) states that at 15° C. 20 milligrams of chlorpicrin per liter caused the death of all termites (*Leucotermes lucifugus* Rossi) in 2 hours. Smaller concentrations required longer time. Four and one-half milligrams per liter killed the insects or poisoned them beyond recovery in 24 hours. At 20° C., 2 milligrams per liter killed the insects in 12 hours.

Neifert and Garrison (1920) compared chlorpicrin with hydrocyanic acid and, in general, for the fumigation of stored products found it more poisonous to insects than the cyanide.

Chapman and Johnson (1925) have corroborated and extended some of the experiments of Bertrand, Brocq-Rousseu, and Dassonville, and found as well that the time to secure a 100 per cent kill and the concentration of the chlorpicrin bear an inverse ratio to each other. They state that "considering time, temperature, and concentration, a low value for any one could be compensated for by a correspondingly high value to one or more of the others." No relationship was found between relative humidity and toxicity. At low concentrations chlorpicrin showed variations in the time necessary to secure 100 per cent kills, but at high concentrations it was very definite and exact in that respect. It was pointed out that the susceptibility of different species of insects is different, and that the confused flour beetle (*Tribolium confusum* Duv.) is more resistant than the grain weevils and requires from 30 to 50 per cent more chlorpicrin to kill it.

Altho the number of references to carbon disulphide in the literature is very large, there is little definite information on the minimum time required to kill at different temperatures or at different concentrations.

Hinds (1909) called attention to the importance of temperature in carbon disulphide fumigations. In this article he gives the minimum time to kill 100 per cent of *Bruchus chinensis* L. as 43 minutes, presumably at a temperature of 68° F. in saturated air.

Hinds and Turner (1910) again pointed out the importance of temperature in fumigating with carbon disulphide. They showed that even high concentrations at low temperatures failed to kill *Sitophilus oryza* L. and stated that "it requires but a few hours to kill the weevils if a strength of gas equal to one-quarter of a saturated atmosphere can be maintained and providing the temperature is high enough to insure a considerable degree of vitality on the part of the insects."

Chittenden (1911, pp. 37-38 and 42-46) showed that poor results with carbon disulphide were secured at temperatures below 50° F. even when a large amount of the fumigant was used.

Portchinsky (1913) found that at 14°-16° R. (64°-68° F.) in a tight place, it was necessary to apply not less than 7 pounds of carbon disulphide per 1000 cubic feet to kill stored products insects in 48 hours. To kill in 24 hours, 10.5 pounds was necessary.

Girault (1912a, p. 77) states that "our recent experiments carried on with great care and duplicated many times have convinced us that an effective fumigation requires 10 pounds of carbon disulphide to every 1000 cubic feet of space to be treated. At this strength we have found the fumigant effective against all granary pests and at all temperatures."

Larson (1924) found that large quantities of beans required a longer exposure or a greater quantity of the fumigant, but that small quantities could be successfully rid of weevils with 3 pounds of carbon disulphide per 1000 cubic feet of space at 58° F. in 24 hours, or with 1.5 pounds in 48 hours.

Neifert and associates (1925) found carbon disulphide far more toxic than carbon tetrachloride. In one instance carbon tetrachloride at the rate of 8.58 pounds per 1000 cubic feet at 30° C. failed to kill any *Sitophilus oryza* L. or *S. granarius* L. in 24 hours. However, a concentration of 29.41 pounds at 23.5° C. killed 100 per cent of the *S. oryza, S. granarius,* and *Tribolium confusum* Duv. present. On the other hand, carbon disulphide at the rate of 2.33 pounds per 1000 cubic feet at 27.5° C. killed 100 per cent of *S. oryza, S. granarius,* and *Plodia interpunctella* Hbn. in 24 hours. These particular experiments were carried out in glass flasks.

Back and Cotton (1925) have compared a mixture of ethyl acetate and carbon tetrachloride with carbon disulphide but did not determine the minimum time to kill with either substance.

Evidently Britton (1908, p. 275) was the first to substitute carbon tetrachloride for carbon disulphide. He reported experiments with tetrachloride when used as a fumigant against scale insects.

Morse (1910) was the first to report the results of using carbon tetrachloride instead of carbon disulphide against museum pests. He found that where 1 pint of the disulphide was sufficient for 50 cubic feet of space, 1 quart of the tetrachloride was required in order to secure the same killing strength.

Shafer (1915, pp. 61-63) reports on some experiments carried on with carbon tetrachloride in 1910 at the Michigan Agricultural College. A series of comparative tests showed that six times as much tetrachloride as disulphide was necessary to accomplish the same results at about 70° F.

Chittenden and Popenoe (1911), with 1.5 pounds of carbon tetrachloride per 1000 cubic feet, did not secure a kill of *Orysaephilus surinamensis* L. or *Laemophloeus minutus* Oliv. in 48 hours, or with twice that amount. With 6 pounds per cubic feet the larvae of *Tenebroides* were unharmed, less than half of the larvae of *Ephestia kuehniella* Zell. were killed, and the common weevils found in grain were living, altho they seemed to be paralyzed. The period of exposure in this case was 24.5 hours. At 10 pounds per 1000 cubic feet, bean weevils (*Bruchus quadrimaculatus* Fab.) were killed in 24 hours, but Cadelle larvae (*Tenebroides mauritanicus* L.) moved slowly after the fumigation. The temperatures during these experiments were not given.

Numerous other authors have made the general statement that carbon tetrachloride can be used as a substitute for carbon disulphide, but all agree that it must be applied in much greater amounts.

Experiments Conducted as a Means of Determining the Relative Toxicity of Carbon tetrachloride, Carbon disulphide, and Chlorpicrin at Different Temperatures

The experiments were performed within a constant temperature and humidity cabinet. The insects used were adult confused flour beetles (*Tribolium confusum* Duv.) taken from one infestation, feeding on cornmeal. The reasons for selecting this species were its availability and the fact that other investigators had found *Tribolium* to be more resistant to the action of chlorpicrin than many other insects (Moore, 1918; Bertrand, Brocq-Rousseu, and Dassonville, 1919a). Altho the species is undoubtedly also resistant toward the action of carbon disulphide and carbon tetrachloride, it was thought to be as good a basis as any on which to compare toxicity.

Method

The apparatus within which the insects were actually subjected to the action of the fumigants and which was used within the constant temperature and humidity machine is shown in Figure 1. This consisted, essentially, of a large bell jar and a ground-glass plate on which the bell jar rested.

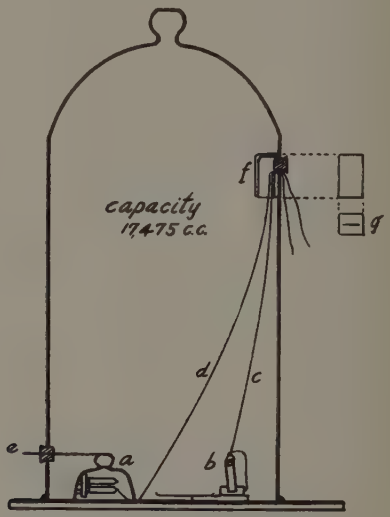


Fig. 1. Diagram of Fumigation Chamber

This chamber was so designed as to shield the insects during the evaporation of the liquid fumigant and to permit the withdrawal of individual cages after various exposures.

Five adults of the confused flour beetle were placed in each of from 10 to 14 cylindrical cages, 1.5 inches long and 0.5 inch in diameter, which were made of rather coarse bolting cloth. These cages were all connected at intervals of 35 inches to a linen thread (d) in order that they could be withdrawn from the bell jar after various lengths of time. The cages containing the insects were implaced on a rack within a very small bell jar shown at "a", which at the beginning of the experiment was sealed to the ground-glass plate with plasticine. From the knob on this small bell jar a cord (e) extended through a rubber stopper which was inserted in a hole through the fumigation jar. The insects were put in the small ball jar to protect them from the action of the gas until the gas had reached its full strength by the complete evaporation of the liquid, in which form it was applied.

The liquid fumigant was measured with a 1-cc. pipette having a glass stop-cock at the lower end, and graduated to 0.01 cc.[2] The ma-

[2] The smallest amount of any material measured in this set of experiments was 0.16 cc. or, in later experiments with the same pipette, 0.08 cc.

terial was measured directly into a small glass vial (b) to which was attached a thread (c) running to the outside of the large jar. By means of this thread the vial could be uncorked and its contents dumped on crumpled filter paper.

The threads (c and d) ran first through a slit (g) in the rubber dam with which the lower end of the trap (f) was covered and thence through a hole in the large jar which was fitted with a rubber stopper. This part of the apparatus was designed to prevent, as far as possible, loss of fumigant when a cage containing insects was withdrawn.

After the small bell jar was in place and the fumigant was in the vial and tightly stoppered, the entire apparatus was placed in the temperature cabinet. The large jar was then raised about ten inches from the ground-glass plate and left in that position long enough for the apparatus to come to the temperature of the cabinet and the air within the fumigation jar to assume the same relative humidity as the air in the cabinet. Then the large jar was lowered on the base plate and sealed around the edges with plasticine. The thread (c) which uncorked the vial and applied the liquid, was next pulled. When the last trace of liquid had evaporated, and after a few minutes additional time had been allowed, the cord (e) was pulled and the actual fumigation of the insects began. By means of that cord the small jar was not only pulled loose from the base plate but was also made to stand up on its side. In this way the cages of insects on the rack within the jar were lifted well off the floor of the fumigatorium.

Near the attachment of the first cage of insects to the thread (d) was also attached a small glass tube closed at the ends with bolting cloth and containing 5 adult beetles. Immediately after the small bell jar was raised, this tube was drawn to such a position that the insects within it could be easily observed by the operator standing outside the glass door of the temperature cabinet. With chlorpicrin, this observation vial was of considerable aid in estimating the time to begin the periodic withdrawal of the cages. But with carbon disulphide and, particularly, with carbon tetrachloride, the time necessary to cause the insects in the observation vial to become inactive seemed to bear little or no relation to the time necessary to kill them.

After each vial was withdrawn it was left beside the fumigation jar until the completion of the experiment. Then the insects were removed from the cages[3] and placed in short glass vials which were kept at room temperature (22° C.) for 24 hours. At the end of that period the percentage of insects killed was noted.

[3] On account of the adsorption of the gases, especially chlorpicrin, on the cages, it was necessary to heat them for a time after each experiment in order to make sure that when they were again sealed in the small jar enough gas would not be released to cause an error in the experiments. For the same reason all parts of the apparatus where any adsorption could take place were heavily coated with paraffin.

Materials Used

The chlorpicrin used was furnished by a chemical company of New York State. The carbon disulphide and carbon tetrachloride were technical grades obtained from the chemical storehouse, University of Minnesota.

Manner of Checking Temperature and Percentage of Relative Humidity

As the air in the type of constant temperature and humidity machine used is continually in motion at the rate of about 15 feet per second, a very even temperature is maintained through the cabinet. The recording thermometer (dry bulb) was checked with a standard centigrade thermometer suspended within the cabinet. The percentage of relative humidity, as shown by the readings of the recording wet and dry bulb thermometers, was checked by a set of standard wet and dry bulb thermometers situated in the air stream near the top of the cabinet.

In a few cases the wet bulb temperature showed considerable variation, indicating changes in relative humidity; but in all such cases, previous to and at the time of lowering the large bell jar to the base plate, a relative humidity of 50 per cent obtained. After the jar was sealed and as long as a constant temperature was maintained, the relative humidity within the fumigation jar remained at 50 per cent. On all the charts, small variations in the wet bulb temperature were due to having the door of the cabinet open long enough to withdraw one of the cages.

Details of Experiments on Toxicity

The first experiments were conducted at 30° C. and several concentrations of each fumigant were tried in order to select concentrations for all tests which would not require too greatly extended periods but which would fall, nevertheless, within the limits of concentrations commonly recommended for these fumigants. Perhaps 15 pounds per 1000 cubic feet for carbon disulphide was a little high. However, it was not expected that the toxicity of this material would be as well maintained as it was in the lower temperatures or 10 pounds per 1000 cubic feet would have been used. Concentrations greater than 15 pounds per 1000 cubic feet are often recommended for carbon disulphide. (See tables in Appendix, pages 32 to 44.)

Summary of Results of Toxicity Experiments on Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride

The results of the experiments on toxicity are summarized in Table I.

The curves shown on Figure 2 were plotted from the data of Table I.

TABLE I

MINIMUM TIME REQUIRED TO SECURE 100 PER CENT KILL OF *Tribolium confusum* DUV.
(Concentrations in pounds per 1000 cubic feet)

Temp. °C.	Chlorpicrin 1 lb.		Chlorpicrin 2 lb.		Chlorpicrin 3 lb.		Carbon disulphide 15 lb.		Carbon tetrachloride 20 lb.	
	hr.	min.	hr.	min.	hr.	min.	hr.	min.	hr.	min.
35	1	15	..	31	..	15*	..	..	..	..
						21	..	30	1	30
30	1	45	..	35	..	25	..	45	3	15
25	2	15	..	50	..	30	1	00*	7	00
							1	30	..	..
20	2	45	1	10	..	40	2	00	12	00?
15	3	50	2	00	1	00	3	00	..	..
10	4	30	2	40	1	20	3	30	..	..

* In cases where 100 per cent kills were followed by percentages less than 100, both times when the first complete kills occurred were recorded.

A comparison of the three fumigants at different concentrations at a temperature of 30° C. is given in Table II.

TABLE II

MINIMUM TIME REQUIRED TO KILL 100 PER CENT OF *Tribolium confusum* DUV.

Concentration per 1000 cu. ft.	Chlorpicrin	Carbon disulphide	Carbon tetrachloride
lb.	hr. min.	hr. min.	hr. min.
1	1 45		
2	35		
	45		
3	25		
4	16		
10		1 05	
		1 30	
15		45	
20		27	3 15
30			2 00
			3 00

Discussion of the Results on Toxicity

From the graphical summary of the results of the toxicity experiments (Figs. 2 and 3), it will be seen that comparisons of these fumigants must be made, not on concentration and time to kill alone, but also on temperature. For instance, at temperatures of 30° and 35° C. carbon tetrachloride shows a fair toxicity. However, considering the way the time to kill with this material decreases toward 25° and 20° C., it is not surprising that very indifferent results have been obtained with it in fumigating at normal temperatures (60° to 70° F.).

On the other hand, attention should be called to the continued high toxicity of carbon disulphide toward the lower temperatures. It was expected that close to 15° C. the time to kill with this fumigant would be greatly increased, but this was not the case. At 10° the insects were killed in 3 hours and 30 minutes with a concentration of 15 pounds per 1000 cubic feet of space. For this reason it seems improbable that many

poor results of grain fumigations carried out at high concentrations but at fairly low temperatures (50° to 60° F.) can be explained solely from the standpoint that at such temperatures carbon disulphide has too low a toxicity, or that the insects are too inactive to be readily affected by the chemical.

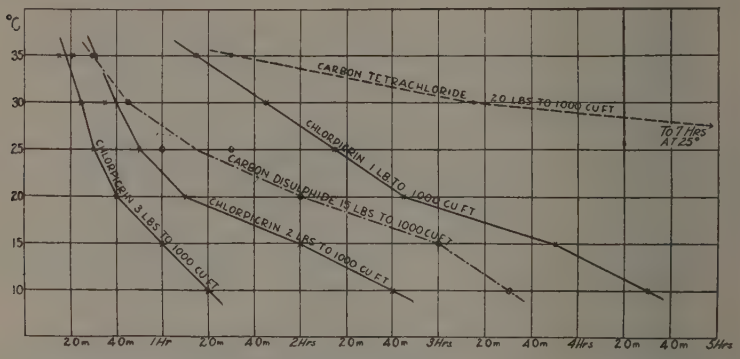


Fig. 2. Time and Temperature Curves for the Toxicity of Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride to *Tribolium confusum* Duv. at the Concentrations Indicated

The time and temperature curves for chlorpicrin (Fig. 3) are not straight line functions such as Bertrand, Brocq-Rousseu, and Dassonville (1919c) show in the case of chlorpicrin at a concentration of 20 grams per cubic meter (about 1.25 pounds per 1000 cubic feet). The

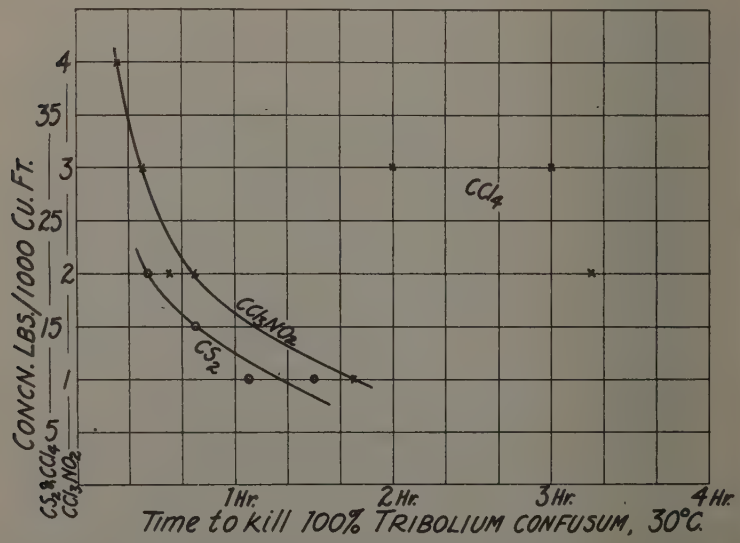


Fig. 3. Time and Concentration Curves for the Toxicity of Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride to *Tribolium confusum* Duv.

rice weevil, *Sitophilus oryza* L., was used by them to test the toxicity, and the difference between that insect and *Tribolium confusum* Duv. may possibly account for the discrepancy. Our general results on toxicity are in agreement with those of Bertrand and Rosenblatt (1919).

We do not believe that the statement of Moore (1918)—that molecule for molecule chlorpicrin is 283 times as toxic as carbon disulphide—is true or that chlorpicrin is 168.4 times as toxic, altho shown definitely enough by his work (Moore, 1917), conveys an entirely correct idea as to the relative toxicities of these two fumigants. On the contrary, we would say that at 20° C. 3 pounds of chlorpicrin per 1000 cubic feet is three times as toxic to insects as 15 pounds of carbon disulphide in the same space at the same temperature. In other words, chlorpicrin at 3 pounds per 1000 cubic feet at 20° C. is about 15 times as toxic as carbon disulphide, pound for pound. But 2 pounds of chlorpicrin at the same temperature is less than 15 times as toxic as a similar amount of carbon disulphide, and with 1 pound of chlorpicrin the ratio is still more reduced. Therefore, it seems unwise to make any definite statement regarding the relative toxicities without limiting it by the factors of temperature and concentration.

Throughout all the experiments a very marked difference was observed between the reaction of the insects to chlorpicrin and to either carbon tetrachloride or carbon disulphide. Even at a temperature of 10° C., which is but 2 or 3 degrees above the minimum effective temperature for *Tribolium confusum,* the insects in the presence of chlorpicrin became very active before death. On the other hand, carbon tetrachloride and carbon disulphide, even at low concentrations, seemed to have an anesthetic effect upon them. In some of the experiments with the tetrachloride, the beetles were inactive for several hours, but upon being taken out of the fumigant and aired they regained their normal activity in a very short time.

DIFFUSION OF CHLORPICRIN, CARBON DISULPHIDE, AND CARBON TETRACHLORIDE IN GRAIN

Historical Summary

Piutti and Mango (1920) state that the action of chlorpicrin when used on cereal at the rate of 20 cc. per cubic meter should be allowed to continue for 8 days where large quantities are to be disinfected. Piutti (1921) says that 20 cc. per cubic meter kills various insects when allowed to act for one week at temperatures from 59° to 68° F., whether the bin is empty or filled with grain. Yamamoto (1922) has said that the active period for chlorpicrin is from 48 to 70 hours, when applied at the rate of 0.225 to 0.35 gram per cubic shaku, which is approximately a concentration of from one-half to three-quarters of a pound

to 1000 cubic feet. Aside from these statements, from which one might infer that some such periods are required for the gas to diffuse through the grain, and Piedallu's (1923) remark about the detection of the odor of the gas at the bottom of a silo three weeks after the material was applied, we have seen no published work regarding the diffusion of this chemical in grain.

Dr. R. N. Chapman, of the Minnesota Agricultural Experiment Station, performed an experiment in July, 1922, which has a direct bearing on this problem. An elevator bin 63 feet high, containing 1000 cubic feet, filled with oats to a height of 60.5 feet, was fumigated with chlorpicrin. The chlorpicrin was diluted with carbon tetrachloride, 1 part chlorpicrin to 4 parts tetrachloride. Seven and one-half pounds of this mixture was applied at the top of the bin. Sacks made of bolting cloth and containing the grain weevil, *Sitophilus granarius* L., were placed at the surface of the grain and 12, 22, 32, 42, 52, and 60 feet below the surface, in order to determine the downward diffusion of the gas. After an exposure of 72 hours the results were as follows:

Distance from surface, ft.	0	12	22	32	42	52	60
Per cent insects dead	100	100	0	50	0	0	3

Moore (1918) says that "one of the chief advantages of carbon disulphide in the fumigation of grain is that its vapor is 2.5 times heavier than air and is thus able to sink down through a large mass of grain. Chlorpicrin vapor is about twice as heavy as that of carbon disulphide." He infers somewhat that the vapor of chlorpicrin should diffuse downward through grain more rapidly than the vapor of carbon disulphide.

General statements regarding the diffusion of carbon disulphide in grain are numerous in the literature. Almost every one who has recommended the use of carbon disulphide as a control measure for insects attacking stored products has stated that the vapors are approximately 2.5 times heavier than air and consequently sink downward through the grain. (Howard, 1893, p. 327; Smith 1896, p. 326; 1900, p. 8; 1903, p. 24; 1908, p. 34; Chittenden, 1897, pp. 22-23; Back, 1919, p. 26; 1922, p. 27; and many others.)

Girault (1912b, p. 87) states that "the vapor of carbon disulphide is a little over 2.5 times heavier than air, a point to be remembered in application, since it goes first to the bottom of the inclosure."

Hinds (1917, pp. 8-9) says "when carbon disulphide is applied to a bin of grain or similar material it has been found that the killing proceeds outward and downward from the point of application of the liquid and forms what may be called a 'cone of killing.' The apex of the cone is close to the point of application, and the base is against the floor or ground below." In the same publication he also states that "in

large masses of corn, containing more than 1000 bushels, where the corn still has the husk on, it is possible to kill enough insects in the interior of the mass to pay for the fumigation, even if the mass is entirely open to the air above and around it. The husks in so large a mass serve to retain the gas long enough to kill weevil, etc."

Dean (1913, pp. 196-197) and King (1920, pp. 12-13), altho stating that the gas is heavier than air and sinks to the lower parts or bottom, are among those who felt the need of getting the carbon disulphide below the surface of the grain.

Fleming (1923) actually measured the diffusion of carbon disulphide in potting soil and, in general, found that the concentration of the gas varied directly with the depth from the surface of the soil and inversely with the distance laterally from the injection hole. He pointed out, however, that his method of measuring diffusion was open to serious objection in that the manner of withdrawing the samples to be analyzed tended to disturb the natural diffusion of the gas in the soil.

Neifert and associates (1925, p. 24) state that "the insecticidal action of a gas is greatly lessened by the presence of grain, probably because the grain absorbs many vapors in large quantities and because the grain mechanically interferes with the diffusion of the gas throughout the receptacle."

Method Used for Estimating Diffusion of Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride

Ordinary methods of gas analysis, such as used by Neifert and Garrison (1920, p. 10) for chlorpicrin or by Fleming (1923, pp. 22-24) for carbon disulphide, did not seem practical in working on the diffusion of gases in grain, chiefly because the samples of gas would have to be withdrawn and thereby natural diffusion would be altered.

During the world war active charcoal, which has the power of adsorbing almost any gas at an astonishing rate, was developed for use in gas masks. Since the war such active charcoals, manufactured as more or less standard products, have come into wide use in industry. Because of the great adsorption capacity of this material, it was readily determined that small amounts of it could be used to estimate fairly accurately the concentration of chlorpicrin, carbon disulphide, or carbon tetrachloride in any container. Consequently it was adopted as the best means at our disposal for working on the diffusion of gases in grain.

Tests of Known Concentrations of Gases Under Various Constant Temperatures with Active Charcoal

Method.—The active charcoal was held in glass tubes which were 2 cm. in inside diameter and 6.5 cm. long. This size was selected so that it could be used later in a grain sampler. Approximately 10 cc. of charcoal was used in one tube. After filling, the tube was closed

tightly with a rubber stopper and weighed accurately to 0.0001 gram. A weight close to 5 grams was obtained by adding or taking out the small amount usually necessary. The stopper was removed just before the charcoal was exposed to a gas and replaced immediately after. After the exposure the tube was re-weighed and the adsorption in milligrams on 5 grams of charcoal in one hour was determined.

The supply of active charcoal was kept in a dessicator jar tightly sealed with vaseline. None of the charcoal was used more than once. The charcoal was not dessicated.

In making the tests, wide-mouthed bottles, with a capacity of 8650 cc. were used (Fig. 4). A tube of charcoal was placed in the container (a), which consisted of a large glass tube held firmly to the bottom of the jar with surgeon's tape. About the tube of charcoal a slightly larger tube was kept in order to prevent contamination from handling. As soon as the tube of charcoal with its protecting tube was placed in the container (a), the latter was tightly closed with a rubber stopper. To make the stopper especially tight, a small amount of vaseline was applied to it. From the stopper a cord extended through the cork used later to close the bottle at the top.

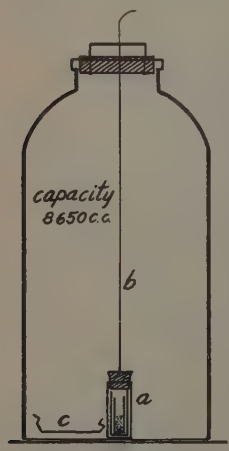


Fig. 4. Diagram of Apparatus in Which Tubes of Charcoal Were Exposed to Known Concentrations of Chlorpicrin, Carbon Disulphide, and Carbon Tetrachloride Under Constant Temperature and Humidity Conditions

A set of three of these bottles was placed in the temperature cabinet. The large corks at this stage of the operation were hung directly over the bottles by means of the wire loops which may be seen in the diagram. The cord (b) running through each cork was long enough that the stopper in the container (a) was not disturbed by the suspension of the cork several inches above the bottle. Time was allowed for the apparatus to assume the temperature and humidity conditions of the cabinet. In order to know when this stage had been reached, a thermometer was fastened inside of one of the bottles in such a position that it could be read through the glass door of the temperature cabinet. The closely fitting heavily paraffined corks were than put rather lightly in place.[4] Following this, the cork to each bottle was raised just enough to drop a small vial containing the correct amount of the fumigant on the filter paper at the bottom of the bottle. Then the corks were pushed down firmly and sealed with plasticine.

[4] The surgeon's tape used to hold the glass container to the bottom of the bottle was also painted with melted paraffin, for without that treatment it absorbed chlorpicrin very readily.

When all the liquid had evaporated, the cord (b) running from each bottle was pulled in order to remove the stopper from the container (a). Thus the charcoal was not exposed until the gas had reached its full concentration.

As adsorption is very closely related to temperature—the lower the temperature the greater the adsorption—the first work consisted in detemining the adsorption at different known concentrations of chlorpicrin, carbon disulphide, and carbon tetrachloride at temperatures of 15°, 20°, 25°, 30°, and 35° C. The details of these experiments are shown in Tables I to XVI, pages 45 to 59, in the Appendix.

From the data presented in these tables, it was possible to plot the adsorption on 5 grams of active charcoal during one hour against the concentration of the gas and obtain for five different temperatures, covering a range from 15° to 35° C., curves from which unknown concentrations of any one of the three gases could be estimated. These curves are shown in Figures 5, 6, 7, 8, 9, and 10.

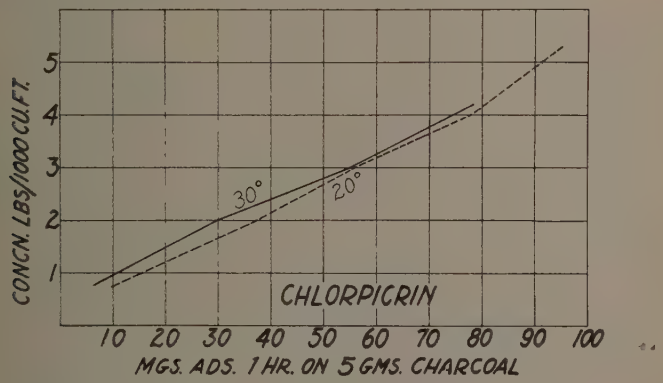


Fig. 5. Adsorption Isotherms for Chlorpicrin Constructed for Estimation of Unknown Concentrations

Experiments on the Diffusion of Chlorpicrin and Carbon Disulphide in a Column of Grain

Equipment Used and Manner of Handling Active Charcoal

In testing the diffusion of chlorpicrin and carbon disulphide in a column of grain, the cylindrical bin (Fig. 11) was used. This was 5 feet high and 14.75 inches in diameter and had a capacity of very slightly less than 6 (5.978) cubic feet. It was constructed of two lengths of glazed sewer pipe placed on a wooden platform. The tile fitted very snugly together, but the narrow cracks between the two tile and between the lower tile and the platform were made air-tight with plasticine. An opening was provided at the bottom of the bin for emptying it, but the trap door for the opening was so built that it could be sealed absolutely tight.

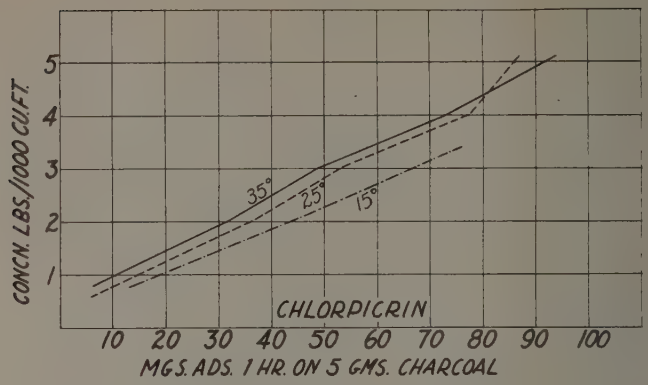


Fig. 6. Adsorption Isotherms for Chlorpicrin Constructed for the Estimation of Unknown Concentrations

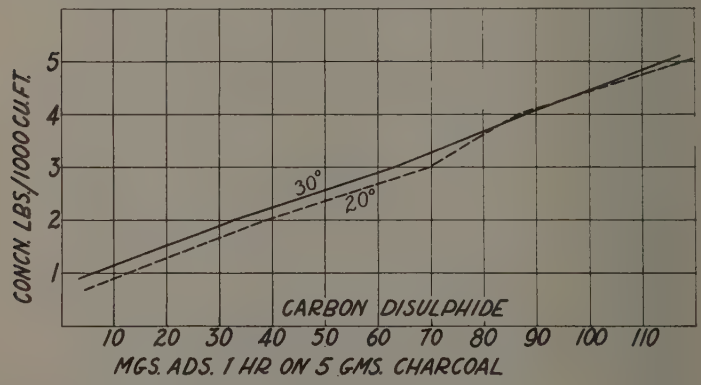


Fig. 7. Adsorption Isotherms for Carbon Disulphide Constructed for the Estimation of Unknown Concentrations

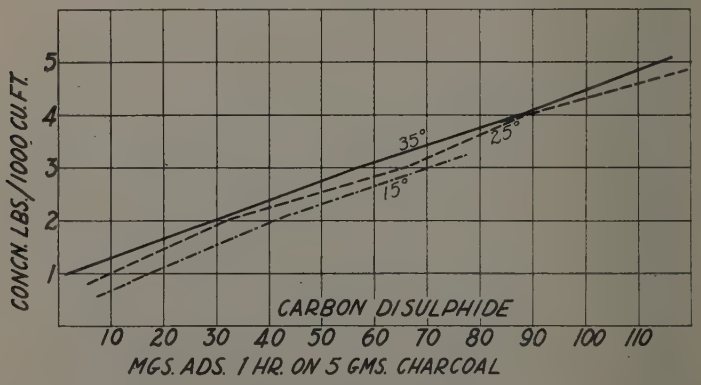


Fig. 8. Adsorption Isotherms for Carbon Disulphide Constructed for the Estimation of Unknown Concentrations

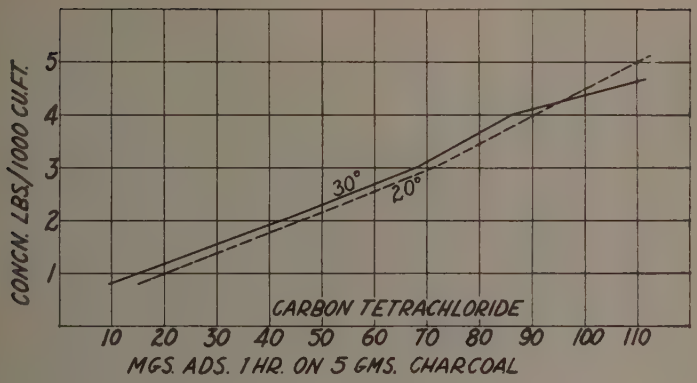


Fig. 9. Adsorption Isotherms for Carbon Tetrachloride Constructed for the Estimation of Unknown Concentrations

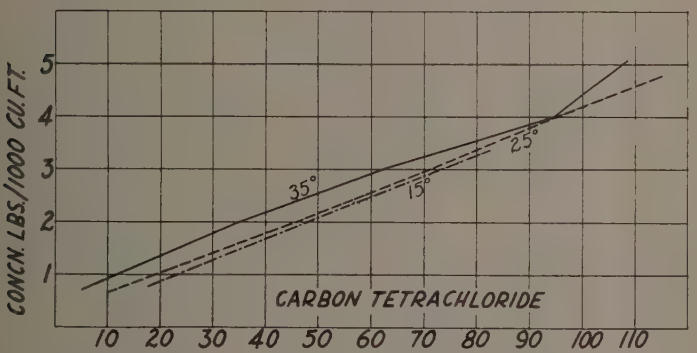


Fig. 10. Adsorption Isotherms for Carbon Tetrachloride Constructed for the Estimation of Unknown Concentrations
The abscissas show milligrams of gas adsorbed on 5 grams of charcoal in one hour.

At the beginning of each experiment in which grain was used, the bin was filled and time was allowed for the grain to settle. Next, the grain was leveled off so that it stood within about 4 inches of the top of the bin. A galvanized iron cover was provided. In this cover were two holes, one large enough for the grain sampler to pass through, and one smaller, through which the stem of a small atomizer, by which the fumigant was applied, could be inserted. After the grain was in the bin, the lid was sealed on. In most of the experiments a test was next made of the adsorption on tubes of charcoal placed in the bin for one hour. Following this check of the adsorption on the charcoal when no fumigant was present, a cover was placed over the hole used for the insertion of the grain sampler and a measured amount of the fumigant was applied.

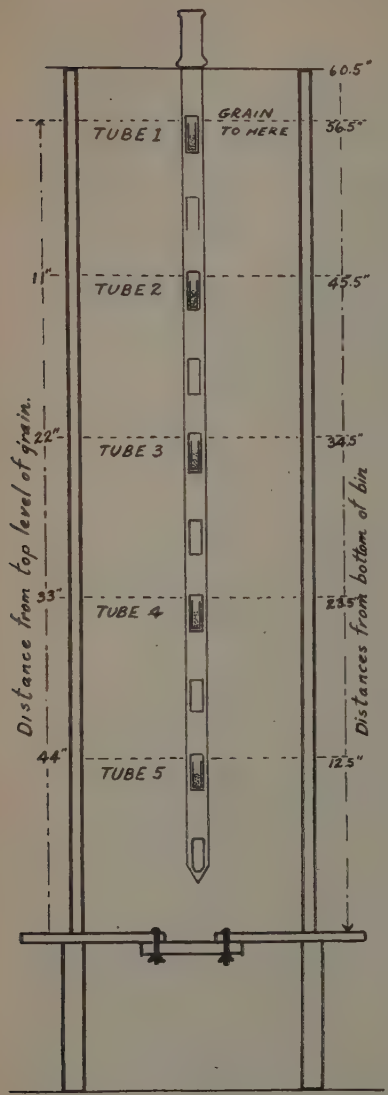


Fig. 11. Diagram of Fumigation Chamber
In this chamber the diffusion of chlorpicrin, carbon disulphide, and carbon tetrachloride in grain was measured by the adsorption of the gases on active charcoal at known depths in a grain sampler.

The use of the grain sampler to lower the tubes of charcoal into the grain is shown in Figure 11. Wire screening was used to prevent the grain from entering the sampler after it was inserted into the grain and opened by revolving the handle. Pieces of screening were cut considerably larger than the openings to the compartments and, when inserted inside, were pressed outward against the inner tube of the sampler. The screens could be pushed up within the compartments far enough to allow the placing or removal of the charcoal tubes.

Test of Apparatus

In order to test out the apparatus, the following preliminary experiment was performed. The trap door at the bottom of the bin was put in place, the top was sealed on with plasticine, and the hole in the top for insertion of the grain sampler was closed. Chlorpicrin at the rate of 3 pounds to 1000 cubic feet was then atomized into the empty bin. After an interval of two hours, tubes of charcoal were placed in the sampler in the positions of tubes 1, 3, and 5, as shown in Figure 11, and the sampler was then lowered into the bin. After an exposure of one hour the tubes were withdrawn and reweighed. The results were as follows:

Temperature, °C.	Position of tube	Weight of charcoal	Increase per 5 gm. charcoal	Approximate concentration per 1000 cu. ft.
		gm.	mg.	lb.
20.5	1	4.9651	18.8	1.17
	3	4.8196	26.6	1.5
	5	4.9974	24.3	1.4

It was immediately seen that the concentration of the gas was not holding up. As the bin was as nearly gas-tight as it could be made, it was thought that adsorption by the tile walls of the bin might account for the loss of the gas. Consequently the bin was shellacked heavily on the inside and the test was repeated. The results follow:

Temperature, °C.	Position of tube	Weight of charcoal	Increase per 5 gm. charcoal	Approximate concentration per 1000 cu. ft.
		gm.	mg.	lb.
20	1	4.9721	52.0	2.8
	2	5.0021	56.3	3.0
	3	5.0110	57.7	3.1

From this it was concluded that the bin was holding the gas satisfactorily.

Diffusion Experiments with Chlorpicrin

Experiment 1.—In the first experiment with grain in the bin, the chlorpicrin was poured directly on the grain instead of being atomized, as in the later experiments. Marquis wheat was used. The chlorpicrin was applied at the rate of 3 pounds per 1000 cubic feet (4.84 cc.). Tests with the charcoal were run during the 2d and 12th hours of the fumigation.

Tube No.	Distance below surface of grain	Weight of charcoal	Increase per 5 gm. charcoal	Maximum concentration per 1000 cu. ft.
	in.	gm.	mg.	lb.
1	0	4.8720	25.3	1.5
2	11	4.8103	4.2	
3	22	4.6920	2.7	Less than 0.4
4	33	4.6739	3.8	
5 (lost)				
Temperature 2d hour of fumigation, 25.5° C.				
1	0	5.0351	7.4	Less than 0.7
2	11	5.0129	6.3	
3	22	5.1469 (spilled)		
4	33	4.8507	6.6	
5	44	5.1109	2.9	
Temperature 12th hour of fumigation, 24.5° C.				

Experiment 2.—Marquis wheat. Chlorpicrin was atomized over the top of the wheat at the rate of 3 pounds per 1000 cubic feet. A tube of charcoal in the position of Tube 3 (Fig. 11), 22 inches below the surface of the wheat, showed previously an increase on 5 grams of 4.1 milligrams. (For an explanation of the value of the check tubes used before fumigations, see the discussion of the results on diffusion.)

Tests were made during the 2d, 5th, 8th, 12th, and 24th hours of the fumigation as follows:

Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal	Maximum concentration per 1000 cu. ft.
		in.	gm.	mg.	lb.
2d	23.3	0	5.0192	101.6 More than	5
		11	4.9149	25.4	1.5
		22	5.0491	3.2	
		33	4.8865	3.5 Less than	0.5
		44	4.9359	0.9	
5th	26.6	0	4.8001	26.5	1.55
		11	4.7715	21.2	1.3
		22	4.9419	6.9	
		33	4.8664	6.4 Less than	0.6
		44	4.9410	4.1	
8th	26.6	0	5.0598	17.5	1.1
		11	4.8939	14.7	1.0
		22	4.9164	9.0	
		33	4.9499	8.3 Less than	0.7
		44	4.9814	5.9	
12th	26.6	0	4.9893	11.1	0.8
		11	4.8548	8.3	
		22	4.8188	5.3 Less than	0.6
		33	5.0560	6.5	
		44	4.9944 (lost)		
24th	21.6	0	4.7796	6.1	
		11	4.8445	5.9	
		22	4.9088	2.9 Less than	0.5
		33	4.8449	5.2	
		44	4.8410	3.6	

At the completion of the diffusion tests in this experiment, three lots of insects, each containing 10 *Sitophilus oryza* L. and 5 *S. granarius* L. were placed in the positions of tubes 1, 3, and 5, or 0, 22, and 44 inches below the surface of the grain, respectively, for 24 hours. All were killed.

Experiment 3.—In this experiment the weighed amounts of charcoal were put in place in the grain sampler. Then in the usually vacant compartments below those holding the charcoal, five lots of insects (*Tribolium confusum* Duv.) were placed. The sampler was lowered into the grain but before being opened, 3 pounds of chlorpicrin to 1000 cubic feet (4.84 cc.) was applied with the atomizer at the top of the bin. Then the sampler was opened and allowed to remain open for 12 hours. With the charcoal exposed to chlorpicrin for such a length of time we can not estimate the values of the increases on the charcoal. They may be taken, however, to have some relative values as to the distribution of the gas. The results follow:

Temperature, °C.	Distances below surface of grain		Increase per 5 gm. charcoal	Per cent dead
	Charcoal tubes	Insect tubes		
	in.	in.	mg.	
20-25	0*			
	11	16.5	99.0	100
	22	27.5	100.7	100
	33	38.5	82.3	†
	44	49.5	48.1	0

* This tube was omitted on account of high concentration at top of bin.
† Slight movement, all died later.

Experiment 4.—Marquis wheat was in the bin. Chlorpicrin at the rate of 3 pounds to 1000 cubic feet (4.84 cc.) was applied at the top of the bin with an atomizer. Tests on the diffusion of the gas were made during the 2d, 5th, 8th, 12th, and 24th hours. The results were as follows:

Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal		Maximum concentration per 1000 cu. ft.
		in.	gm.	mg.		lb.
2d	19.5	0	5.1681	102.3	More than	5
		11	5.0846	9.8		
		22	5.0689	2.8	Less than	0.7
		33	5.0085	9.5		
		44	4.9496	7.2	Less than	0.6
5th	20.5	0	5.1240	70.7		3.7
		11	5.0036	20.6		1.2
		22	4.9982	16.5		1.0
		33	4.9719	11.1		0.7
		44	4.9641	9.4		0.6
8th	20.3	0	4.8314	40.2		2.15
		11	4.8396	17.7		1.1
		22	4.8765	11.0		0.7
		33	4.8536	8.0	Less than	0.6
		44	4.8726	7.8		
12th	20.5	0	4.9479	27.5		1.55
		11	5.1064	13.7		0.9
		22	5.0398	10.4		
		33	5.0182	8.8	Less than	0.8
		44	4.9033	9.1		
24th	19.5	0	4.9364	13.7		0.87
		11	4.8156	4.5		
		22	4.9037	2.8	Less than	0.5
		33	5.0322	3.0		
		44	4.9661	1.5		

During the interval between the 12th and 24th hours of the fumigation, a period of 11 hours, open vials containing confused flour beetles (*Tribolium confusum* Duv.) were kept in the positions of 0, 11, 22, 33, and 44 inches below the surface of the grain. On examination immediately after the sampler containing them was withdrawn, those in the upper three vials were dead, those that had been 33 inches below the surface were very evidently affected, but those from 44 inches below

the surface were perfectly normal. Forty-eight hours later 40 per cent of the beetles from 33 inches below the surface were dead.

At the beginning of the experiment, a sample of wheat withdrawn from the bin had a moisture content of 11.6 per cent. A sample taken at the conclusion of the experiment showed a moisture content of 10.75 per cent.[5]

Experiment 5.—About 5 pints of wheat were withdrawn from the fumigation bin at the conclusion of Experiment 4. When the wheat was withdrawn and the sampler emptied, the grain from the different compartments was kept separate. The wheat from 1 to 11 inches below the surface was placed in Bottle No. 1, that from 11 to 22 inches in Bottle No. 2, from 22 to 33 inches in Bottle No. 3, from 33 to 44 inches in Bottle No. 4, and from 44 to 55 inches in Bottle No. 5. Before being placed in the bottles the wheat was aired for two hours by being spread out in shallow piles on a table. In each bottle with the wheat were released 10 rice weevils (*Sitophilus oryza* L.) and somewhat later 5 confused flour beetles (*Tribolium confusum* Duv.). A check was kept with wheat which had not been fumigated. After various periods of time the grain in each bottle was aired about 3 hours, the percentage of dead insects was recorded, and then the wheat and fresh live insects were put back in the bottle. The results were as follows:

		Wheat Withdrawn and Put in Bottles with Insects, August 25, 1924					
		Per cent dead, Aug. 26 (24 hours)		Per cent dead, Aug. 28 (72 hours)		Per cent dead, Aug. 30 (5 days)	
Bottle No.	Depth in bin	Sitophilus	Tribolium*	Sitophilus	Tribolium	Sitophilus	Tribolium
	in.						
1	0-11	100	...	100	100	100	100
2	11-22	100	...	100	60	100	20
3	22-33	100	...	100	20	100	0
4	33-44	100	...	100	0	50	0
5	44-55	100	...	50	0	20	0
Check		0	...	0	0	0	0

		Per cent dead, Sept. 6 (12 days)		Per cent dead, Sept. 10 (16 days)	
Bottle No.	Depth in bin	Sitophilus	Tribolium	Sitophilus	Tribolium
	in.				
1	0-11	100	100	80	0
2	11-22	100	40	60	0
3	22-33	100	20	20	0
4	33-44	100	0	20	0
5	44-55	100	0	30	0
Check		0	0	0	0

* Put in on Aug. 26.

The experiment shows very plainly that chlorpicrin must have been taken up by the wheat in considerable quantity to kill 80 per cent of the weevils 16 days after being fumigated and after a total of 14

[5] The writer is indebted to the Division of Agricultural Biochemistry for the determinations of moisture content.

hours airing. Even tho *Sitophilus oryza* L. is undoubtedly more susceptible to chlorpicrin than *Tribolium confusum* Duv., the much greater mortality of the *Sitophilus* in this experiment may have been due to their feeding on the grain, whereas *Tribolium* did not. The fact that *Tribolium* were killed shows that chlorpicrin, as a gas, was present in the bottles. The odor of chlorpicrin was very evident in the bottles holding samples of wheat taken from near the top of the bin.

Diffusion Experiments with Carbon Disulphide

Experiment 6.—The experiments with carbon disulphide were performed with the same kind of wheat as was used in the chlorpicrin experiments. Carbon disulphide was used in the fumigation bin at the rate of 3 pounds to 1000 cubic feet, or 6.5 cc. This low concentration was used in order to observe more closely the diffusion of the gas. Tests for diffusion were made during the 2d, 5th, and 24th hours. Before the application of the disulphide, a test was made of the adsorption of moisture by the charcoal.

Check on Adsorption of Moisture					
Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal	Maximum concentration per 1000 cu. ft.
		in.	gm.	mg.	lb.
	22.5	0	5.1854	3.0	
		11	5.0621	6.2	
		22	5.0290	5.9	
		33	5.0335	8.5	
		44	5.1160	6.3	
2d	22.5	0	5.1884	158.4	More than 5
		11	5.0683	24.8	1.5
		22	5.0359	3.7	Less than 0.7
		33	5.0420	2.8	
		44	5.0420	3.1	
5th	24.5	0	5.0317	68.8	3.12
		11	4.9815	30.8	2.0
		22	4.8654	15.3	1.27
		33	4.9775	12.3	1.12
		44	4.8967	12.3	1.12
24th	27	0	4.9018	16.1	1.3
		11	4.7470	13.0	1.2
		22	4.8611	10.1	1.05
		33	5.0957	10.4	1.06
		44	5.0750	8.6	0.95

Experiment 7.—Carbon disulphide was used at the rate of 3 pounds to 1000 cubic feet, or 6.5 cc., in the fumigation bin. Marquis wheat was used. Tests for diffusion were made at the 2d, 5th, and 24th hours. Check on moisture, etc., was made first.

Check on Adsorption of Moisture

Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal		Maximum concentration per 1000 cu. ft.
		in.	gm.	mg.		lb.
	25	■	5.0025	6.0		
		11	5.0047	6.2		
		22	5.0010	6.4		
		33	5.0018	6.8		
		44	5.0010	5.7		
2d	25	0	5.0035	93.6		4.15
		11	5.0011	16.9		1.35
		22	5.0053	16.1		1.3
		33	4.9983	10.4		1.07
		44	4.9987	5.1	Less than	0.9
5th	26	0	5.0019	56.2		2.75
		11	4.9926	19.6		1.47
		22	5.0002	10.6		1.07
		33	5.0011	6.7	Less than	0.9
		44	4.9984	7.4		
24th	26	0	5.0000	9.8		1.03
		11	5.0027	9.1		1.0
		22	5.0024	8.3		
		33	4.5999	2.3	Less than	0.9
		44	5.0011	3.3		

Diffusion Experiments with Carbon Tetrachloride

The following experiment was performed with carbon tetrachloride in the diffusion chamber at the rate of three pounds per 1000 cubic feet. As near as could be determined the wheat was similar to that used in former experiments.

Check on Adsorption of Moisture

Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal		Maximum concentration per 1000 cu. ft.
		in.	gm.	mg.		lb.
	23	0	5.0062	7.0		
		11	5.0107	5.0		
		22	5.0009	8.2		
		33	5.0062	6.5		
		44	5.0092	6.2		
2d	23	0	5.0065	78.4		3.3
		11	4.9880	33.2		1.5
		22	5.0101	34.1		1.5
		33	5.0046	18.3		1.0
		44	5.0092	10.4	Less than	0.8
5th	22	0	5.0007	34.3		1.5
		11	4.9958	18.2		1.0
		22	5.0017	12.9		
		33	5.0062	15.1	Less than	1.0
		44	5.0102	14.0		
12th	22	0	4.9890	10.2		
		11	5.0020	14.0	Less than	1.0
		22	5.0100	9.5		
		33	5.0062	10.1		
		44	5.0020	8.7		
24th	23	0	5.0091	6.1		
		11	5.0076	12.0		
		22	4.9992	9.2	Less than	1.0
		33	4.9982	7.1		
		44	5.0009	10.2		

As the concentration of the fumigant used in the previous experiment was far below what would be toxic to insects, in another experiment the wheat in the fumigation chamber was treated with carbon tetrachloride at the rate of 30 pounds per 1000 cubic feet. The adsorption on the charcoal shows at least the relative concentrations at the different depths. The amount of gas adsorbed during the fifth hour was so small that no further determinations were made.

Hour	Temperature, °C.	Distance below surface	Weight of charcoal	Increase per 5 gm. charcoal	Approximate maxmium concentration per 1000 cu. ft.
		in.	gm.	mg.	lb.
2d	24	0	5.0069	58.3	2.5
		22	4.9985	143.5	
		44	4.9976	126.4	
5th	24	0	5.0041	21.0	1.1
		22	5.0094	13.0	Less than 0.8
		44	4.9992	26.0	1.3

Discussion of Results of Diffusion Experiments

Probable error in the use of active charcoal.—Whether the increases in weight were due to moisture or to the adsorption of the fumigant could not be determined in the tubes of charcoal showing a small concentration. However, even with some water vapor taken up, the increases on the charcoal would show maximum concentrations. Cheney, Ray, and St. John (1923) have shown that active charcoal possesses the quality of selectivity. For instance, when it is added to a mixture of water and benzene, it accepts the benzene but rejects the water. Whether or not this is true of the adsorption of these gases in preference to water vapor we do not know.

General results.—The gases undoubtedly diffuse downward, but comparatively slowly at ordinary temperatures. There is little foundation, so far as we have determined, for the statement that because the vapors formed by the evaporation of such substances as chlorpicrin or carbon disulphide are several times heavier than air, they therefore always will sink rapidly to the bottom of a bin containing cereal grain.

The concentration of carbon disulphide in a tight bin covered at the top is not greater at the bottom of the bin than toward the top. On the contrary, the concentration of the gas at the end of the 2d, 5th, or 24th hour of the fumigation is inversely proportional to the depth below the surface of the grain.

The experiments on carbon tetrachloride show a stronger tendency for a downward movement of the gas than was the case with chlorpicrin or carbon disulphide. But what is perhaps even more important, the second experiment gives an idea of the great amount of fumigant taken up by the grain.

The diffusion downward seems to be closely related to the adsorption of the fumigant by the grain. Theoretically, the higher the temperature the less the adsorption, consequently there should be a greater tendency for the fumigant to diffuse through the entire mass of grain. On the other hand, the lower the temperature the greater the adsorption, and the tendency for the gas to diffuse would be diminished.

Table III shows the relation of temperature to the adsorption of chlorpicrin, carbon disulphide, and carbon tetrachloride on active charcoal.

TABLE III

QUANTITY ADSORBED BY 5 GRAMS OF ACTIVE CHARCOAL IN ONE HOUR
(Concentration 1 Pound to 1000 Cubic Feet)

Temperature, °C.	CS_2 mg.	CCl_3NO_2 mg.	CCl_4 mg.
35	1.8	10.3	11.8
30	5.7	10.6	14.9
25	9.2	14.7	19.6
20	12.4	15.6	20.2
15	17.1	18.9	22.0

These data are shown in Figure 12. It will be seen that at 15° C 9.5 times more carbon disulphide was adsorbed than at 35°, about 1.8 times as much chlorpicrin, and nearly twice as much carbon tetrachloride. The amount of adsorbent used, 10 cc., was only one eighthundred sixty-fifth of the volume of the container. From these data it seems probable that altho wheat has unquestionably a very small fraction of the adsorption power of active charcoal, when a bin is full of wheat and a fumigant is applied, the wheat, as the adsorbent, is

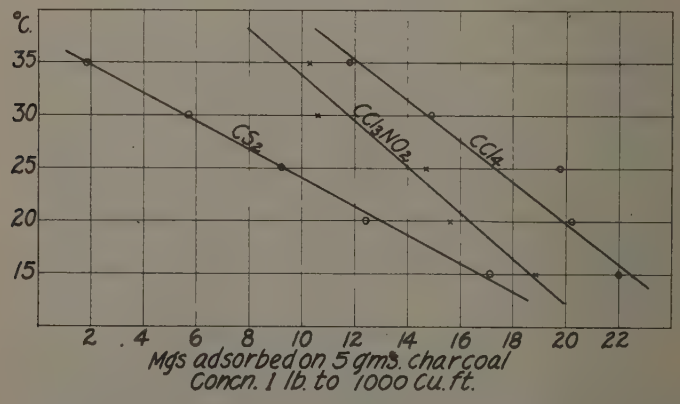


Fig. 12. Curves Showing the Relation of Temperature to the Adsorption of Chlorpicrin Carbon Disulphide, and Carbon Tetrachloride on Active Charcoal

affected by temperature in some such ratio. The temperature used in the fumigation of grain—merely from the standpoint of diffusion—seems to be particularly important in the case of carbon disulphide. Added weight is given to this viewpoint by the fact that carbon disulphide maintains its toxicity to insects at fairly low temperature, as previously shown.

Hinds (1917) is probably correct in his explanation regarding the effectiveness of carbon disulphide when applied to large masses of corn. From what we have found, the fumigation of such large piles of unbinned corn for protection against weevil should be most successful at lower temperatures, that is, temperatures from 60° to 70° F. rather than above 80° F.

CONCLUSIONS

The toxicity of chlorpicrin, carbon disulphide, and carbon tetrachloride to insects can be correctly compared only when concentration, time to kill, and temperature are all considered as factors.

Throughout a range of temperatures from 35° to 10° C., 1 pound of chlorpicrin is more toxic to the confused flour beetle (*Tribolium confusum* Duv.) than 20 pounds of carbon tetrachloride, and the lower the temperature the greater the relative toxicity. Throughout the same range of temperatures, chlorpicrin at the rate of 1 pound to 1000 cubic feet of space is less toxic than carbon disulphide at the rate of 15 pounds per 1000 cubic feet.

The greater the concentration of chlorpicrin (between 1 and 3 pounds per 1000 cubic feet) the better is its toxicity to insects maintained through a range in temperatures from 35° to 10° C.

A decrease in temperature lowers the toxicity of carbon tetrachloride much more rapidly than that of carbon disulphide or chlorpicrin.

When time to kill 100 per cent of *Tribolium confusum* Duv. with chlorpicrin, carbon disulphide, or carbon tetrachloride is plotted against temperature, the result is not a straight line. Between 35° and 10° C. the time increases at a greater rate toward the lower temperatures.

When chlorpicrin or carbon disulphide is applied to wheat in a tight bin, the downward diffusion of the gas is not so rapid as ordinarily described.

The concentration of the gases does not become stronger at the bottom of a bin of wheat than toward the top, but varies inversely with the depth below the surface of the grain.

Adsorption of the gases by the top layers of grain prevents their rapid downward movement.

As adsorption is closely related to temperature (the lower the temperature the greater the adsorption) temperature is an important factor in the fumigation of grain aside from its relation to the toxicity of the fumigant or the activity of the insects being fumigated.

LITERATURE CITED

Back, E. A.
1919 Conserving corn from weevils in the Gulf Coast States. U. S. Dept. of Agr., Farmers Bull. 1029, 36 pages.

———
1922 Weevils in beans and peas. U. S. Dept. of Agr., Farmers Bull. 1275, 35 pages.

——— and Cotton, R. T.
1925 A newly recommended fumigant, ethyl acetate in combination with carbon tetrachloride. Jour. Ec. Ent., 18:302-307.

Bertrand, G., Brocq-Rousseu, and Dassonville
1919a Destruction de la Punaise des lits (*Cimex lactularius* Mer.) par la Ch'oropicrine. Compt. rend. 169:441-443.

———, Brocq-Rousseu and Dassonville
1919b Influence de la temperature et d'autres agents physiques sur le pouvoir insecticide de la chloropicrine. Compt. rend. 169:1059-1061.

———, Brocq-Rousseu, and Dassonville
1919c Action comparee de la chloropicrine sur le charancon et sur le Tribolium. Compt. rend. 169:1428-1430.

——— and Rosenblatt, Mme. M.
1919 Action texique comparee de quelques substances volatiles sur divers insectes. Compt. rend 168:911-913.

Britton, W. E.
1908 7th Rept. of the state entomologist of Connecticut, for the year 1907. pp. 265-338.

Burchardt, F.
1920 Erfahrungen mit dem Chlorpikrin als Mittel sur Bekämpfung tierisches Schädlinge. Deutsche landw. Presse, 47:417.

Cheney, N. K., Ray, A. B., and St. John, A.
1923 The properties of activated charcoal which determine its industrial application. Jour. Ind. and Eng. Chem. 12:1244-1255.

Chapman, R. N. and Johnson, A. H.
1925 Possibilities and limitations of chlorpicrin as a fumigant for cereal products. Jour. Agr. Res. 31:745-760.

Chittenden, F. H.
1897 Some insects injurious to stored grain. U. S. Dept. of Agr., Farmers Bull. 45. 24 pages.

———
1911 The lesser grain borer. The larger grain borer. U. S. Dept. of Agr., Bull. 96, part 3, pp. 29-52.

——— and Popenee, C. H.
1911 Carbon tetrachloride as a substitute for carbon disulphide in fumigation against insects. U. S. Dept. of Agr. Bull 96, part 4, pp. 53-57.

Dean, G. A.
1913 Mill and stored grain insects. Kan. Agr. Expt. Sta. Bull. 189, pp. 139-236.

Feytaud, J.
1920 Sur la destruction des Termites par la chloropicrine. Compt. rend. 171:440-442.

Fleming, W. E.
1923 Fumigation of potting soil with carbon bisulphide for the control of the Japanese beetle. N. J. Agr. Expt. Sta. Bull. 380. 45 pages.

Girault, A. A.
1912a Insects injurious to stored grains and their ground products. 27th Rept. State Entomologist of Illinois. 143 pages.

———
1912b Insects injurious to stored grains and their ground products. Ill. Agr. Expt. Sta. Bull. 156, pp. 67-92.

Hinds, W. E.
1909 Carbon di-sulfid fumigation of grain infesting insects. Jour. Ec. Ent., 2:161-165.

———
1917 Carbon disulphid as an insecticide. U. S. Dept. of Agr., Farmers Bull. 799. 24 pages.

——— and Turner, W. F.
1910 Carbon di-sulfid fumigation for the rice weevil in corn. Jour. Ec. Ent. 3:47-56.

Howard L. O.
1893 Angoumois moth or fly weevil. Insect Life 5:325-328.

King, J. L.
1920 The angoumois grain moth. Pa. Dept. Agr. Circ. 1. 14 pages.

Larson, A. O.
1924 Fumigation of bean weevils, *Bruchus obtectus* Say and *B. quadrimaculatus* Fab. Jour Agr. Res., 28:347-356.

Moore, Wm.
1917 Volatility of organic compounds as an index of the toxicity of their vapors to insects. Jour. Agr. Res., 10:365-371.

———
1918 Fumigation with chlorpicrin. Jour. Ec. Ent., 11:357-362.

Morse, A. P.
1910 Carbon tetrachloride vs. carbon disulphide, Jour. Ec. Ent., 3:104.

Neifert, I. E., and Garrison, G. L.
1920 Experiments on the toxic action of certain gases on insects, seeds, and fungi. U. S. Dept. of Agr. Bull. 893, 16 pages.

———, Cook, F. C., Roark, R. C., Tonkin, W. H., Back E. A., and Cotton, R. T.
1925 Fumigation against grain weevils with various volatile organic compounds. U. S. Dept. of Agr. Bull. 1313, 40 pages.

Piedallu, A.
1923 Sur la destruction en grand des parasites des grains. C. r. Acad. Agr., France, 9:364-368.

Piutti, A.
1921 Asione della Chlorpicrina. Riv. di Ampel., Leghorn, 9. Abs. in Riv. Agr., parma, 26:593-994.

——— and Bernardini. R.
1917 Sopra l'Azione della Chloropicrina (Trichloronitrometano) sui Parassiti del Grano. Rend. Acad. Sci. Fis. Mat. Naples, 23:51-53.

——— and Mango, A.
1920 Employment of chlorpicrin in disinfection of cereals. Giorn. Chim. ind. applicata, 2:677-682. (In Italian)

Portchinsky, I. A.
1913 Insects injurious to grain in stores and warehouses. Memoirs of the Bur. of Ent. of the Sc. Comm. of the Central Board of Land Adm. and Agr. St. Petersburg, 10. (In Russian) Abs. R. A. E. 2:39-41.

Shafer, G. D.
1915 How contact insecticides kill. Mich. Agr. Expt. Sta. Tech. Bull 21 67 pages.
Smith, J. B.
1896 Economic entomology. J. B. Lippincott Co., Phila. 481 pages.
———
1900 The angoumois grain moth. N. J. Agr. Expt. Sta. Bull. 147. 8 pages
———
1903 Insecticides and their use. N. J. Agr. Expt. Sta. Bull 169. 27 pages
———
1908 Insecticide materials and their application, with suggestions for practice. N. J. Agr. Expt. Sta. Bull. 213. 46 pages.
Wille, J.
1921a Chlorpikrin als Schädlungsbekämpfungsmittel in Seinen Wirkungen auf Tier und Pflanze. Die Naturwissenschaften, 9:41-48.
———
1921b Chlorpikrin in der Schädlungsbekämpfang ins besondere im Kampf gegen den Körnkajer (*C. granaria* L.) Zeitschrift für Angewandte Entomologie, 7:296-310.
Yamamoto, Ryo.
1922 Insecticide use of chlorpicrin. Rikwagaku Kenkyujo Iho, 1:1-8 (In Japanese.)

APPENDIX

Experiments with Chlorpicrin

(See page 10.)

Experiment 1. Concentration 1 lb. to 1000 cu. ft. Temperature 35° C. R. H. 50%
CCl_3NO_2 Applied 7:59 p.m. Insects exposed at 8:10 p.m.

Cage No.	Taken out, p.m.	Exposure hr.-min.	% Dead
1	9:00	45	0
2	9:05	55	0
3	9:10	1:00	60
4	9:15	1:05	60
5	9:25	1:15	100
6	9:35	1:25	100
7	9:40	1:30	100
8	9:45	1:35	100
9	9:50	1:40	100
10	9:55	1:45	100

The *Tribolium* in the observation vial were still very active at the end of 50 minutes

Experiment 2. Concentration 2 lb. to 1000 cu. ft. Temperature 35° C. R. H. 50% CCl_3NO_2 applied 9:25 a.m. Insects exposed at 9:40 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		min.	
1	9:55	15	20
2	9:59	19	60
3	10:03	23	60
4	10:07	27	20
5	10:11	31	100
6	10:15	35	100
7	10:19	39	100
8	10:23	43	100
9	10:27	47	100
10	10:31	51	100

Experiment 3. Concentration 3 lb. to 1000 cu. ft. Temperature 35° C. R. H. 50% CCl_3NO_2 applied 1:50 p.m. Insects exposed at 2:02 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	2:05	3	0
2	2:08	6	0
3	2:11	9	20
4	2:14	12	80
5	2:17	15[1]	100
6	2:20	18	80
7	2:23	21[1]	100
8	2:26	24	100
9	2:29	27	100
10	2:32	30	100

[1] In cases such as this both times were recorded on the graph showing comparative toxicities. See Figure 2.

Experiment 4. Concentration 1 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_3NO_2 applied 3:52 p.m. Insects exposed at 4:05 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	4:30	25	20
2	4:40	35	20
3	4:50	45	50
4	5:00	55	60
5	5:10	1:05	60
6	5:20	1:15	70
7	5:30	1:25	90
8	5:40	1:35	80
9	5:50	1:45	100
10	6:00	1:55	100

In this experiment as well as in experiments 5, 6, and 7 ten insects were in each cage.

Experiment 5. Concentration 2 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_3NO_2 applied 3:45 p.m. Insects exposed at 4:05 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	4:15	10	10
2	4:20	15	20
3	4:25	20	10
4	4:30	25	30
5	4:35	30	60
6	4:40	35	100
7	4:45	40	90
8	4:50	45	100
9	4:55	50	100
10	5:00	55	100

Experiment 6. Concentration 3 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_3NO_2 applied 8:40 p.m. Insects exposed at 8:51 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	8:56	5	0
2	9:01	10	60
3	9:06	15	70
4	9:11	20	40
5	9:16	25	100
6	9:21	30	100
7	9:26	35	100
8	9:31	40	100
9	9:36	45	100
10	9:41	50	100

Experiment 7. Concentration 4 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_3NO_2 applied 3:29 p.m. Insects exposed at 3:48 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	3:52	4	50
2	3:56	8	40
3	4:00	12	90
4	4:04	16	100
5	4:08	20	100
6	4:12	24	100
7	4:16	28	100
8	4:20	32	100
9	4:24	36	100
10	4:25	40	100

Experiment 8. Concentration 1 lb to 1000 cu. ft. Temperature 25° C. R. H. 50% CCl_3NO_2 applied 4:45 p.m. Insects exposed at 5:00 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	6:15	1:15	20
2	6:45	1:45	80
3	7:15	2:15	100
4	7:25	2:25	100
5	7:35	2:35	100
6	7:40	2:40	100
7	7:45	2:45	100
8	7:50	2:50	100
9	7:55	2:55	100
10	8:00	3:00	100

Experiment 9. Concentration 2 lb. to 1000 cu. ft. Temperature 25° C. R. H. 50% CCl_3NO_2 applied 9:45 p.m. Insects exposed at 10 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:30	30	0
2	10:40	40	80
3	10:50	50	100
4	11:00	1:00	100
5	11:05	1:05	100
6	11:10	1:10	100
7	11:15	1:15	100
8	11:20	1:20	100
9	11:25	1:25	100
10	11:30	1:30	100

Experiment 10. Concentration 3 lb. to 1000 cu. ft. Temperature 25° C. R. H. 50% CCl_3NO_2 applied 1:05 a.m. Insects exposed at 1:30 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		min.	
1	1:40	10	0
2	1:45	15	40
3	1:50	20	80
4	1:55	25	60
5	2:00	30	100
6	2:05	35	100
7	2:10	40	100
8	2:15	45	100
9	2:20	50	100
10	2:25	55	100

Experiment 11. Concentration 1 lb. to 1000 cu. ft. Temperature 20° C. R. H. 50% CCl_3NO_2 applied 5:30 p.m. Insects exposed at 6:00 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	8:15	2:15	80
2	8:30	2:30	80
3	8:45	2:45	100
4	9:00	3:00	100
5	9:15	3:15	100
6	9:30	3:30	100
7	9:45	3:45	100
8	10:00	4:00	100
9	10:15	4:15	100
10	10:30	4:30	100

Experiment 12. Concentration 2 lb. to 1000 cu ft. Temperature 20° C. R. H. 50% CCl_3NO_2 applied 11:45 a.m. Insects exposed at 12:15 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	12:55	40	0
2	1:05	50	40
3	1:10	55	20
4	1:15	1:00	60
5	1:20	1:05	80
6	1:25	1:10	100
7	1:30	1:15	100
8	1:35	1:20	100
9	1:40	1:25	100
10	1:45	1:30	100

Experiment 13. Concentration 3 lb. to 1000 cu. ft. Temperature 20° C. R. H. 50% CCl_3NO_2 applied 12:15 a.m. Insects exposed at 12:45 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		hr.-min.	
1	1:10	25	0
2	1:15	30	80
3	1:20	35	80
4	1:25	40	100
5	1:30	45	100
6	1:35	50	100
7	1:40	55	100
8	1:45	1:00	100
9	1:50	1:05	100
10	1:55	1:10	100

Experiment 14. Concentration 1 lb. to 1000 cu ft. Temperature 15° C. R. H. 50% CCl_3NO_2 applied 10:00 a.m. Insects exposed at 10:25 a.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	12:30	2:05	40
2	1:00	2:35	60
3	1:15	2:50	60
4	1:30	3:05	80
5	1:45	3:20	60
6	2:00	3:35	80
7	2:15	3:50	100
8	2:30	4:05	100
9	2:45	4:20	100
10	3:00	4:35	100

Experiment 15. Concentration 2 lb. to 1000 cu. ft. Temperature 15° C. R. H. 50% CCl_3NO_2 applied 6:10 p.m. Insects exposed at 9:10 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:15	1:05	20
2	10:30	1:20	80
3	10:40	1:30	80
4	10:50	1:40	80
5	11:00	1:50	80
6	11:10	2:00	100
7	11:20	2:10	100
8	11:30	2:20	100
9	11:40	2:30	100
10	11:50	2:40	100

Experiment 16. Concentration 3 lb. to 1000 cu. ft. Temperature 15° C. R. H. 50% CCl_3NO_2 applied 12:10 p.m. Insects exposed at 1:50 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min	
1	2:20	30	0
2	2:25	35	20
3	2:30	40	20
4	2:35	45	40
5	2:40	50	20
6	2:45	55	80
7	2:50	1:00	100
8	2:55	1:05	100
9	3:00	1:10	100
10	3:05	1:15	100

Experiment 17. Concentration 1 lb. to 1000 cu. ft. Temperature 10° C. R. H. 50% CCl_3NO_2 applied 6:15 p.m. Insects exposed at 6:45 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	8:45	2:00	0
2	9:45	3:00	0
3	10:15	3:30	40
4	10:45	4:00	40
5	11:00	4:15	80
6	11:15	4:30	100
7	11:30	4:45	100
8	11:45	5:00	100
9	12:00 m.	5:15	100
10	12:15 a.m.	5:30	100

Experiment 18. Concentration 2 lb. to 1000 cu. ft. Temperature 10° C. R. H. 50% CCl_3NO_2 applied 8:30 p.m. Insects exposed at 9 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:30	1:30	
2	11:00	2:00	80
3	11:30	2:30*	80
4	11:40	2:40	100
5	11:50	2:50	100
6	12:00	3:00	100
7	12:10	3:10	100
8	12:20	3:20	100
9	12:30	3:30	100
10	12:40	3:40	100

* One beetle was particularly active here immediately after the cage containing it was withdrawn from the fumigation jar. Those in cage No. 2 were all active when withdrawn.

Experiment 19.* Concentration 3 lb. to 1000 cu. ft. Temperature 10° C. R. H. 50% CCl_3NO_2 applied 12:55 a.m. Insects exposed at 1:20 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		hr.-min.	
1	2:00	40	40
2	2:10	50	60
3	2:20	1:00	..
4	2:30	1:10	80
5	2:35	1:15	80
6	2:40	1:20	100
7	2:45	1:25	100
8	2:50	1:30	100
9	2:55	1:35	100
10	3:00	1:40	100

* On account of the insects being left in the cages for several hours following the completion of this experiment and the fact that the smell of chlorpicrin seemed to be rather strong on the cages when examined, another trial was made. However, the second trial gave almost identical results.

Experiments with Carbon Disulphide

Experiment 20. Concentration 15 lb. to 1000 cu. ft. Temperature 35° C. R. H. 50%
CS_2 applied 9:45 p.m. Insects exposed at 9:55 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	10:00	5	0
2	10:05	10	0
3	10:10	15	20
4	10:15	20	40
5	10:20	25	80
6	10:25	30	100
7	10:30	35	100
8	10:35	40	100
9	10:40	45	100
10	10:45	50	100

Experiment 21.* Concentration 10 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50%
CS_2 applied 9:10 p.m. Insects exposed at 9:15 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:00	45	80
2	10:15	60	69
3	10:25	1:10	80
4	10:35	1:20	50
5	10:45	1:30	100
6	10:55	1:40	100
7	11:00	1:45	100
8	11:05	1:50	100
9	11:10	1:55	100
10	11:15	2:00	100

* On account of the high percentage of kill, even at 45 minutes, in this experiment it was repeated as follows:

CS_2 applied at 11:15 a.m. Insects exposed at 11:20 a.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	12:05	45	40
2	12:15	55	80
3	12:25	1:05	100
4	12:35	1:15	100

One hundred per cent was killed in the six other cages taken out at intervals up to 1 hour and 50 minutes. The results of both these trials are recorded on Figure 3.

Experiment 22. Concentration 15 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CS_2 applied at 9:25 p.m. Insects exposed at 9:30 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	9:40	10	0
2	9:45	15	80
3	9:50	20	20
4	9:55	25*	100
5	10:00	30	60
6	10:05	35	60
7	10:10	40	80
8	10:15	45	100
9	10:20	50	100
10	10:25	55	100

* Both of these periods are recorded on Figure 2.

Experiment 23. Concentration 20 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CS_2 applied 2:27 p.m. Insects exposed at 2:33 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		min.	
1	2:43	10	60
2	2:50	17	40
3	2:55	22	80
4	3:00	27	100
5	3:05	32	100
6	3:10	37	100
7	3:15	42	100
8	3:20	47	100
9	3:25	52	100
10	3:30	57	100

Experiment 24. Concentration 15 lb. to 1000 cu. ft. Temperature 25° C. R. H. 50% CS_2 applied 9:15 p.m. Insects exposed at 9:30 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:00	30	0
2	10:10	40	20
3	10:20	50	60
4	10:30	1:00*	100
5	10:40	1:10	100
6	10:50	1:20	80
7	11:00	1:30*	100
8	11:10	1:40	100
9	11:20	1:50	100
10	11:30	2:00	100

* Both these periods are recorded on Figure 2.

Experiment 25.* Concentration 15 lb. to 1000 cu. ft. Temperature 20° C. R. H. 50% CS_2 applied 4:00 a.m. Insects exposed at 4:00 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		hr.-min.	
1	5:30	1:30	60
2	6:00	2:00	100
3	6:30	2:30	100
4	7:00	3:00	100
5	7:30	3:30	100
6	8:00	4:00	100
7	10:00	6:00	100
8	11:00	7:00	100
9	12:00 m.	8:00	100
10	1:00 p.m.	9:00	100

* This experiment was performed in a large wide-mouthed bottle, 8650 cc. capacity. The evaporation of CS_2 is so rapid that the short time that the insects were exposed before the gas was full strength would make little, if any, difference. The other apparatus was in use at the same time.

Experiment 26. Concentration 15 lb. to 1000 cu. ft. Temperature 15° C. R. H. 50% CS_2 applied and insects exposed at 11:50 a.m.
(Performed in the same container as Experiment 25.)

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	1:50	2:00	40
2	2:50	3:00	100
3	3:50	4:00	100
4	4:50	5:00	100
5	5:50	6:00	100
6	6:50	7:00	100
7	7:50	8:00	100

Experiment 27. Concentration 15 lb. to 1000 cu. ft. Temperature 10° C. R. H. 50% CS_2 applied and insects exposed at 8:30 p.m.
(The same container was used as in the two previous experiments.)

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	10:00	1:30	0
2	10:30	2:00	0
3	11:00	2:30	0
4	11:30	3:00	40
5	11:40	3:10	60
6	11:50	3:20	40
7	12:00 m.	3:30	100
8	12:10 a.m.	3:40	100
9	12:20	3:50	100
10	12:30	4:00	100

Experiments with Carbon Tetrachloride

Experiment 28. Concentration 20 lb. to 1000 cu. ft. Temperature 35° C. R. H. 50%
CCl_4 applied 3:50 p.m. Insects exposed at 4:06 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	5:36	1:30	100
2	5:45	1:39	100
3	5:54	1:48	100

Cages 4 to 10, taken out at intervals up to 2:51, showed 100 per cent kill. For thi reason the experiment was repeated and the cages were taken out at shorter periods of time The results follow:

CCl_4 applied at 10:04 a.m. Insects exposed at 10:15 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		hr.-min.	
1	10:35	20	0
2	10:45	30	20
3	10:55	40	0
4	11:00	45	20
5	11:05	50	0
6	11:10	55	0
7	11:15	1:00	20
8	11:20	1:05	0
9	11:25	1:10	0
10	11:30	1:15	0

It is evident that the real minimum of time to kill was missed in both of these exper ments. One hour and 30 minutes, the time obtained from the first part of this experiment, wa used on Figure 2.

Experiment 29. Concentration 1 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50%

Insects were exposed as in the other experiments for periods up to 5 hours and 2 minutes. Not a single specimen died.

Experiment 30. Concentration 4 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50%

The insects were exposed to the fumigant as in the other experiments for periods up t 4 hours and 15 minutes. Not a single specimen died.

Experiment 31. Concentration 10 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50%

The insects were exposed to the fumigant for periods up to 7 hours. Altho they a became inactive in less than 2 hours, when the first cage was removed, none were killed up t 4 hours and 30 minutes and only 20% in 7 hours.

Experiment 32. Concentration 20 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_4 applied 10:14 a.m. Insects exposed at 10:50 a.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	11:45 a.m.	1:15	40
2	12:00 m.	1:30	60
3	12:15	1:45	20
4	12:30	2:00	40
5	12:45	2:15	40
6	1:00	2:30	60
7	1:15	2:45	80
8	1:30	3:00	80
9	1:45	3:15	100
10	2:00	3:30	100

Experiment 33. Concentration 30 lb. to 1000 cu. ft. Temperature 30° C. R. H. 50% CCl_4 applied 1:33 p.m. Insects exposed at 1:45 p.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	2:45	1:00	60
2	3:00	1:15	0
3	3:15	1:30	80
4	3:30	1:45	60
5	3:45	2:00	100
6	4:00	2:15	100
7	4:15	2:30	80
8	4:30	2:45	60
9	4:45	3:00	100
10	5:00	3:15	100

Experiment 34. Concentration 20 lb. to 1000 cu. ft. Temperature 25° C. R. H. 50% CCl_4 applied 11:25 a.m. Insects exposed at 11:45 a.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	1:15	1:30	0
2	1:35	1:50	0
3	1:50	2:05	20
4	2:05	2:20	0
5	2:20	2:35	20
6	2:35	2:50	0
7	2:55	3:10	20
8	3:05	3:20	20
9	3:20	3:35	40
10	3:30	3:45	60

As a 100% kill was not obtained, the experiment was repeated as follows: CCl_4 applied 11:25 a.m. Insects exposed at 11:45 a.m.

Cage No.	Taken out, p.m.	Exposure	% Dead
		hr.-min.	
1	2:45	3:00	20
2	3:05	3:20	40
3	3:25	3:40	40
4	3:45	4:00	40
5	4:05	4:20	40
6	4:25	4:40	60
7	4:45	5:00	60
8	5:05	5:20	80
9	5:25	5:40	60
10	5:45	6:00	60
11	6:45	7:00	100
12	7:45	8:00	100

Experiment 35. Concentration 20 lb. to 1000 cu. ft. Temperature 20° C. R. H. 50% CCl_4 applied 3:45 a.m. Insects exposed at 4:00 a.m.

Cage No.	Taken out, a.m.	Exposure	% Dead
		hr.-min.	
1	7:00	3:00	40
2	8:00	4:00	20
3	9:00	5:00	..*
4	10:00	6:00	..
5	11:00	7:00	..
6	12:00 m.	8:00	..
7	1:00 p.m.	9:00	..
8	2:00	10:00	..
9	3:00	11:00	..
10	4:00	12:00	100?
11	5:00	13:00	100
12	6:00	14:00	100
13	7:00	15:00	100
14	8:00	16:00	100

* It was very difficult to tell whether the insects taken from cages 3 to 9 were dead or alive. At the end of 24 hours most of them showed some movement of appendages but so slight that it was impossible to say just where the minimum time to kill 100% occurred.

TABLE I

Gas Adsorbed, Chlorpicrin; Temperature, 35° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6886	4.9984	29.6990	0.0104	10.4	9.7
	2	21.9520	26.9571	5.0051	26.9655	.0084	8.4	
	3	22.0357	27.0484	5.0127	27.0586	.0102	10.2	
2	1	24.6902	29.6927	5.0025	29.7270	.0343	34.3	31.3
	2	21.9520	26.9589	5.0069	26.9917	.0328	32.7	
	3	22.0357	27.0306	4.9949	27.0576	.0270	27.0	
3	1	24.6902	29.6862	4.9960	29.7377	.0514	51.4	48.1
	2	21.9520	26.9652	5.0132	27.0132	.0480	47.9	
	3	22.0357	27.0343	4.9986	27.0794	.0451	45.1	
4	1	24.6902	29.6980	5.0078	29.7734	.0754	75.3	72.5
	1		29.6871	4.9969	29.7567	.0696	69.7	
5	2	21.9520	26.9671	5.0151	27.0584	.0913	91.0	91.0
Check	3	22.0357	27.0430	5.0083	27.0377	—.0053	—5.3	—3.6
	3		27.0280	4.9923	27.0261	—.0019	—1.9	

TABLE II

Gas Adsorbed, Chlorpicrin; Temperature, 30° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6696	5.0094	29.7100	0.0104	10.4	10.6
	2	21.9520	26.9632	5.0112	26.9748	.0116	11.6	
	3	22.0357	27.0307	4.9950	27.0403	.0096	9.6	
	1	24.6902	29.6835	4.9933	29.6936	.0101	10.1	
	2	21.9520	26.9583	5.0063	26.9706	.0123	12.3	
	3	22.0357	27.0247	4.9890	27.0347	.0100	10.0	
2	1	24.6902	29.6936	5.0034	29.7249	.0313	31.3	29.7
	2	21.9520	26.9570	5.0050	26.9851	.0281	28.1	
	3	22.0357	27.0318	4.9961	27.0615	.0297	29.7	
3	1	24.6902	29.6950	5.0048	29.7552	.0602	60.1	55.1
	2	21.9520	26.9629	5.0109	27.0153	.0524	52.3	
	3	22.0357	27.0322	4.9965	27.0851	.0529	52.9	
4	1	24.6902	29.6947	5.0045	29.7700	.0744	74.3	74.3
5	2	21.9520	26.9605	5.0085	27.0384	.0779	77.7*	77.7
Check	3	22.0357	27.0370	5.0013	27.0376	0.0006	0.6	0.6

* Evidently not all of the chlorpicrin was evaporated when the charcoal was exposed.

TABLE III

Gas Adsorbed, Chlorpicrin; Temperature, 25° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6890	4.9988	29.7036	0.0146	14.6	14.7
	2	21.9520	26.9568	5.0048	26.9700	.0132	13.2	
	3	22.0357	27.0322	4.9965	27.0485	.0163	16.3	
2	1	24.6902	29.6952	5.0050	29.7314	.0362	36.1	36.4
	2	21.9520	26.9564	5.0044	26.9952	.0392	39.1	
	3	22.0357	27.0352	4.9995	27.0693	.0341	34.1	
3	1	24.6902	29.6880	4.9978	29.7396	.0516	51.6	52.4
	2	21.9520	26.9535	5.0015	27.0093	.0558	55.8	
	3	22.0357	27.0330	4.9973	27.0830	.0500	50.0	
4	1	24.6902	29.6917	5.0015	29.7690	.0773	77.3	77.3
5	2	21.9520	26.9589	5.0069	27.0450	.0861	85.9	85.9
Check	3	22.0357	27.0358	5.0001	27.0383	0.0025	2.5	2.5

TABLE IV

Gas Adsorbed, Chlorpicrin; Temperature, 20° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6890	4.9988	29.7047	0.0157	15.7	15.6
	2	21.9520	26.9562	5.0042	26.9711	.0149	14.9	
	3	22.0357	27.0318	4.9961	27.0479	.0161	16.1	
2	1	24.6902	29.6882	4.9980	29.7252	.0370	37.0	37.2
	2	21.9520	26.9607	5.0087	26.9973	.0366	36.5	
	3	22.0357	27.0367	5.0010	27.0748	.0381	38.1	
3	1	24.6902	29.6923	5.0021	29.7454	.0531	53.1	56.0
	2	21.9520	26.9530	5.0010	27.0086	.0556	55.6	
	3	22.0357	27.0358	5.0001	27.0950	.0592	59.2	
4	1	24.6902	29.6910	5.0008	29.7689	.0779	77.9	77.9
5	2	21.9520	26.9554	5.0034	27.0469	.0915	91.4	91.4
Check	3	22.0357	27.0375	5.0018	27.0435	0.0060	6.0	6.0

TABLE V

Gas Adsorbed, Chlorpicrin; Temperature, 15° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6865	4.9953	29.7064	0.0199	19.9	18.9
	1		29.6894	4.9992	29.7080	.0186	18.6	
	1		29.6917	5.0015	29.7099	.0182	18.2	
2	2	21.9520	26.9545	5.0025	26.9977	.0432	43.2	43.1
	2		26.9533	5.0013	26.9954	.0421	42.1	
	2		26.9592	5.0072	27.0033	.0441	44.0	
3	3	22.0357	27.0351	4.9994	27.1036	.0685	68.5	66.6
	3		27.0349	4.9982	27.0999	.0650	65.0	
	3		27,0382	5.0025	27.1044	.0662	66.2	
Check	1	24.6902	29.6885	4.9983	29.6935	0.0050	5.0	5.0

TABLE VI

Gas Adsorbed, Carbon Disulphide; Temperature, 35° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6896	4.9997	29.6917	0.0021	2.1	1.8
	2	21.9520	26.9542	5.0022	26.9570	.0028	2.8	
	3	22.0357	27.0458	5.0101	27.0455	— .0003	— .3	
	1	24.6902	29.6923	5.0021	29.6930	.0007	0.7	
	2	21.9520	26.9344	5.0024	26.9561	.0017	1.7	
	3	22.0357	27.0389	5.0032	27.0422	.0033	3.3	
2	1	24.6902	29.6890	4.9988	29.7178	.0288	28.8	29.0
	2	21.9520	26.9596	5.0076	26.9885	.0289	28.8	
	3	22.0357	27.0259	4.9902	27.0554	.0295	29.5	
3	1	24.6902	29.6966	5.0064	29.7558	.0592	59.1	56.7
	2	21.9520	26.9560	5.0040	27.0140	.0580	57.9	
	3	22.0357	27.0365	5.0008	27.0895	.0530	53.0	
4	1	24.6902	29.6879	4.9977	29.7753	.0874	87.4	87.4
5	2	21.9520	26.9516	4.9996	27.0663	1147	114.7	114.7
Check	3	22.0357	27.0338	4.9981	27.0300	—0.0038	—3.8	—3.8

TABLE VII

Gas Adsorbed, Carbon Disulphide; Temperature, 30° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6865	4.9963	29.6929	0.0064	6.4	5.7
	2	21.9520	26.9611	5.0091	26.9667	.0056	5.6	
	3	22.0357	27.0329	4.9972	27.0381	.0052	5.2	
2	1	24.6902	29.6946	5.0044	29.7271	.0325	32.4	32.2
	2	21.9520	26.9556	5.0036	26.9890	.0334	33.3	
	3	22.0357	27.0391	5.0034	27.0702	.0311	31.1	
3	1	24.6902	29.6851	4.9949	29.7504	.0653	65.3	62.9
	2	21.9520	26.9601	5.0081	27.0226	.0625	62.4	
	3	22.0357	27.0360	5.0003	27.0971	.0611	61.1	
4	1	24.6902	29.6836	4.9934	29.7712	.0876	87.7	87.7
5	2	21.9520	26.9544	5.0024	27.0686	.1142	114.2	114.2
Check	3	22.0357	27.0377	5.0020	27.0338	−0.0039	−3.9	−3.9

TABLE VIII

Gas Adsorbed; Carbon Disulphide; Temperature, 25° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6892	4.9990	29.6981	0.0089	8.9	9.2
	2	21.9520	26.9518	4.9998	26.9606	.0088	8.8	
	3	22.0357	27.0304	4.9947	27.0404	.0100	10.0	
2	1	24.6902	29.6898	4.9996	29.7234	.0336	33.6	31.7
	2	21.9520	26.9572	5.0052	26.9898	.0326	32.5	
	3	22.0357	27.0334	4.9977	27.0624	.0290	29.0	
3	1	24.6902	29.6860	4.9958	29.7530	.0670	67.0	65.7
	2	21.9520	26.9525	5.0005	27.0193	.0668	66.8	
	3	22.0357	27.0388	5.0031	27.1022	.0634	63.3	
4	1	24.6902	29.6883	4.9981	29.7763	.0880	88.0	88.0
5	2	21.9520	26.9568	5.0048	27.0820	.1252	125.1	125.1
Check	3	22.0357	27.0332	4.9975	27.0370	0.0038	3.8	3.8

TABLE IX

Gas Adsorbed, Carbon Disulphide; Temperature, 20° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6833	4.9931	29.6961	0.0128	12.8	12.4
	2	21.9520	26.9558	5.0038	26.9677	.0119	11.9	
	3	22.0357	27.0319	4.9962	27.0443	.0124	12.4	
2	1	24.6902	29.6914	5.0012	29.7296	.0382	38.2	38.5
	2	21.9520	26.9511	4.9991	26.9910	.0399	39.9	
	3	22.0357	27.0371	5.0014	27.0745	.0374	37.4	
3	1	24.6902	29.6882	4.9980	29.7574	.0692	69.2	69.7
	2	21.9520	26.9564	5.0042	27.0251	.0687	68.6	
	3	22.0357	27.0384	5.0027	27.1097	.0713	71.3	
4	1	24.6902	29.6907	5.0005	29.7774	.0867	86.7	86.7
5	2	21.9520	26.9556	5.0036	27.0736	.1180	118.0	118.0
Check	3	22.0357	27.0298	4.9941	27.0284	—0.0014	—1.5	—1.5

TABLE X

Gas Adsorbed, Carbon Disulphide; Temperature, 15° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	64.6902	29.6870	4.9968	29.7041	0.0171	17.1	17.1
2	2	21.9520	26.9503	4.9983	26.9912	.0409	40.9	40.9
3	3	22.0357	27.0377	5.0020	27.1084	.0707	70.7	70.7
Check	1	24.6902	29.6914	5.0012	29.6919	0.0005	0.5	0.5

TABLE XI

Gas Adsorbed, Carbon Tetrochloride; Temperature, 35° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6891	4.9989	29.6995	0.0104	10.4	11.8
	2	21.9520	26.9574	5.0054	26.9704	.0130	12.9	
	3	22.0357	27.0322	4.9965	27.0444	.0122	12.2	
2	1	24.6902	29.6937	5.0035	29.7273	.0336	33.6	35.0
	2	21.9520	26.9559	5.0039	26.9924	.0365	36.5	
	3	22.0357	27.0263	4.9906	27.0631	.0348	34.8	
3	1	24.6902	29.6881	4.9979	29.7494	.0613	61.3	61.9
	2	21.9520	26.9598	5.0078	27.0249	.0651	65.0	
	3	22.0357	27.0365	5.0008	27.0960	.0595	59.5	
4	1	24.6902	29.6915	5.0013	29.7860	.0945	94.5	94.5
5	2	21.9520	26.9751	5.0231	27.0829	.1078	107.3	108.3
Check	3	22.0357	27.0396	5.0039	27.0344	—0.0052	—5.2	—5.2

TABLE XII

Gas Adsorbed, Carbon Tetrachloride; Temperature, 30° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6817	4.9915	29.6965	0.0148	14.8	14.9
	2	21.9520	26.9589	5.0069	26.9740	.0151	15.1	
	3	22.0357	27.0245	4.9888	27.0379	.0135	13.5	
	2	21.9520	26.9611	5.0091	26.9786	.0175	17.4	
	3	22.0357	27.0369	5.0012	27.0507	.0138	13.8	
2	1	24.6902	29.6923	5.0021	29.7338	.0415	41.5	42.4
	2	21.9520	26.9664	5.0144	27.0117	.0453	45.2	
	3	22.0357	27.0307	4.9950	27.0713	.0406	40.6	
3	1	24.6902	29.6906	5.0004	29.7623	.0717	71.7	68.0
	2	21.9520	26.9620	5.0100	27.0310	.0690	68.6	
	3	22.0357	27.0304	4.9947	27.0938	.0634	63.4	
4	1	24.6902	29.6847	4.9945	29.7710	.0863	86.4	86.4
5	2	21.9520	26.9567	5.0047	27.0811	.1244	124.3	124.3
Check	3	22.0357	27.0333	4.9976	27.0325	—0.0008	—0.8	—0.8

TABLE XIII

Gas Adsorbed, Carbon Tetrachloride; Temperature, 25° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6885	4.9983	29.7076	0.0191	19.1	19.8
	2	21.9520	26.9524	5.0004	26.9738	.0214	21.4	
	3	22.0357	27.0321	4.9964	27.0508	.0187	18.8	
2	1	24.6902	29.6958	5.0056	29.7437	.0479	46.8	46.3
	2	21.9520	26.9593	5.0073	27.0075	.0462	46.1	
	3	22.0357	27.0317	4.9960	27.0766	.0449	45.0	
3	1	24.6902	29.6914	5.0012	29.7642	.0728	72.6	71.1
	2	21.9520	26.9518	4.9998	27.0218	.0700	70.0	
	3	22.0357	27.0337	4.9980	27.1043	.0706	70.6	
4	1	24.6902	29.6856	4.9954	29.7805	.0949	95.0	95.0
5	2	21.9520	26.9526	5.0006	27.0735	.1209	120.9	120.9
Check	3	22.0357	27.0357	5.0000	27.0329	—0.0028	—2.8	—2.8

TABLE XIV

Gas Adsorbed, Carbon Tetrachloride; Temperature, 20° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6872	4.9970	29.7081	0.0209	20.9	20.2
	2	21.9520	26.9560	5.0040	26.9745	.0185	18.4	
	3	22.0357	27.0332	4.9975	27.0545	.0213	21.3	
2	1	24.6902	29.6910	5.0008	29.7371	.0461	46.1	46.1
	2	21.9520	27.0366	5.0846	27.0822	.0456	45.0	
	3	22.0357	27.0381	5.0024	27.0853	.0472	47.2	
3	1	24.6902	29.6852	4.9950	29.7570	.0718	71.8	71.1
	2	21.9520	26.9520	5.0000	27.0212	.0692	69.2	
	3	22.0357	27.0339	4.9982	27.1062	.0723	72.3	
4	1	24.6902	29.6841	4.9939	29.7740	.0899	90.0	90.0
5	2	21.9520	26.9610	5.0090	27.0709	.1099	109.7	109.7
Check	3	22.0357	27.0359	5.0002	27.0412	.0053	5.3	5.3
	3		27.0369	5.0012	27.0423	0.0054	5.4	

TABLE XV

Gas Adsorbed, Carbon Tetrachloride; Temperature, 15° C.; R. H., 50 per Cent; Time, 1 Hour; Concentration per 1000 Cubic Feet

Concentration	Tube No.	Weight of tube and stopper	Weight of tube, stopper, and charcoal	Net weight charcoal	Second weight total	Increase	Increase per 5 gm. charcoal	Average
lb.		gm.	gm.	gm.	gm.	gm.	mg.	mg.
1	1	24.6902	29.6902	5.0000	29.7112	0.0210	21.0	22.0
	1		29.6919	5.0017	29.7140	.0221	22.1	
	1		28.6897	4.9995	29.7126	.0229	22.9	
2	2	21.9520	26.9550	5.0030	27.0035	.0485	48.5	47.9
	2		26.9510	4.9990	26.9983	.0473	47.3	
	2		26.9599	5.0079	27.0080	.0481	48.0	
3	3	22.0357	27.0371	5.0014	27.1107	.0736	73.6	72.8
	3		27.0392	5.0035	27.1112	.0720	71.9	
	3		27.0394	5.0037	27.1125	.0731	73.0	
Check	1	24.6902	29.6952	5.0050	29.7015	0.0063	6.3	6.3

Technical Bulletin 50 August 1927

University of Minnesota
Agricultural Experiment Station

Heartrot of Aspen

With Special Reference to Forest Management in Minnesota

Henry Schmitz, Division of Forestry
and
Lyle W. R. Jackson, Division of Plant Pathology and Botany

UNIVERSITY FARM, ST. PAUL

CONTENTS

	Page
Introduction	5
Uses of aspen	6
Causes of decay in aspen	6
Field methods	8
Method of compilation	11
Decay of aspen in relation to age	18
Decay of aspen in relation to injuries	31
Root studies	33
Culture studies	37
Histological studies	40
Summary and conclusions	42

ILLUSTRATIONS

		Page
Fig. 1.	Frequency distribution of percentage deviations from the total peeled volume curve	12
2.	Peeled volume in cubic feet of average tree by age classes	13
3.	Volume of rot in cubic feet in entire stem of aspen trees	14
4.	Volume of each stage of rot as a percentage of total rot in entire stem	15
5.	Rot as a percentage of total tree volume	16
6.	Gross periodic growth and periodic decay in aspen trees	22
7.	Volume of rot per acre in well stocked aspen stands on average sites	25
8.	Gross mean annual growth and mean annual decay per acre in well stocked aspen stands on average sites	26
9.	Culmination of gross and net mean annual growth in well stocked aspen stands on average sites	29
10.	Gross periodic annual growth and periodic annual decay per acre in well stocked aspen stands on average sites	30

The writers are greatly indebted to R. M. Brown for valuable assistance in connection with the compilation of the data; to E. M. Freeman, chief of the Division of Plant Pathology and Botany, University of Minnesota, and to Raphael Zon, Director of the Lake States Forest Experiment Station, United States Forest Service, for advice and assistance throughout the course of this study.

HEARTROT OF ASPEN

WITH SPECIAL REFERENCE TO FOREST MANAGEMENT IN MINNESOTA

By Henry Schmitz and Lyle W. R. Jackson

INTRODUCTION

Aspen, or popple (*Populus tremuloides* Michx.), because of the ide area it now occupies, can be considered one of the most important ee species in Minnesota. Altho hardwoods originally occupied ap- roximately only 1,500,000 acres, a comparatively small part of which as in aspen, it is estimated that approximately 50 per cent of the tal forest area of the northern half of the state, or 10,000,000 acres, now in aspen. Aspen will therefore play a very important part any attempt at systematic management of forest lands in Minnesota r the production of wood crops.

Ecologically, the aspen type is usually regarded as temporary, but equent fires tend to make it more nearly permanent. In its conquest the better red and white pine soils in Minnesota, aspen has been aterially assisted through unwise and unregulated cutting and through e injudicious use of fire. Obviously, then, whether or not the acreage w in aspen will increase or decrease in the future depends largely on e protection from fire which these areas receive and upon the silvi- ltural methods employed to convert aspen stands to those of a more luable species. In certain regions and on certain limited areas, this nversion is taking place naturally, but future fires and unwise cutting ethods can easily and quickly undo nature's efforts in this direction. onsidering all the factors involved, there seems to be little likelihood at the aspen acreage in Minnesota will be materially reduced in the ear future.

Unfortunately, there is a prejudice against the use of aspen wood, en for purposes for which it is well suited. This prejudice is due, a considerable extent at least, to its susceptibility to heartrot, resulting a rule in large losses, especially in the older trees.

It is important, therefore, that silvicultural practices and methods of anagement for these stands be worked out which will reduce the losses om decay to a minimum. The primary object of this study was to etermine the extent of these losses and to furnish the pathological data ecessary in devising a rational system of forestry to reduce them.[1]

[1] A comprehensive project, of which this study is only a part, dealing with the growth d yield of aspen in Minnesota, has been undertaken by the Cloquet Forest Experiment Sta- n in co-operation with the Lake States Forest Experiment Station. The results will soon ready for publication.

USES OF ASPEN

Little or no recent information is available concerning the amoun of aspen used in Minnesota for different purposes. It is known gen erally that aspen is quite widely used for fence posts, to some exten for lumber, ties, box shooks, slack cooperage, excelsior, and paper pulp Crocker[2] estimates that the annual consumption of aspen in Minnesot aggregates 105,592 cords. Of this amount, 20,000 cords are used i the manufacture of paper pulp.

It is safe to assume that its use will be more extensive in the future altho aspen has certain characteristics that render it poorly adapted fo certain uses. On the whole it is available only in comparatively sma sizes. The wood is fairly soft, weak, and warps badly in seasoning Furthermore, the wood lacks durability, a condition which ordinaril renders it unfit for fence posts, ties, and similar uses when it must com in contact with the soil. This disadvantage can be largely offset b treating with a wood preservative. It is a significant fact that one larg Canadian railroad system has used treated aspen ties, and, so far a the writers are able to ascertain, has been fairly well satisfied with th results. Should the demand for aspen ties increase, it would creat a good market for the larger sized material.

Aspen is also used in the manufacture of excelsior. No data ar available to show how much is used for this purpose, but it is un doubtedly considerable. There is no reason why the use for thi purpose should not increase.

The use of aspen in the manufacture of wooden boxes in Minnesot is also probably greatly on the increase. In 1913 it was estimated tha 360,000 board feet was used;[3] in 1926, one boxboard mill alone cu more than twice this amount in a single month.

Aspen is also quite extensively used for barn floors and in roug farm buildings. If properly seasoned and kept dry, apparently no grea difficulty is experienced with its use for these purposes.

CAUSES OF DECAY IN ASPEN

In general, three fungi are usually considered to be the cause o most of the decay of aspen heartwood. All are extensively distribute in both the eastern and the western hemispheres. The most importan of these organisms is *Fomes igniarius* (L.) Gillett, which is commo throughout the entire range of aspen and everywhere causes heav losses. Considerably less important is *Armillaria mellea* Vahl., whic

[2] Crocker, D. A. Pulpwood in the Lake States. Woodlands Section, American Pul and Paper Association, Bull. 3. New York. 1926.

[3] Maxwell, H. U. Harris, John T., and Cox, Wm. T. Wood-using industries o Minnesota. St. Paul. 1913.

commonly causes a root rot of many deciduous and coniferous trees, but which may also cause butt rot in aspen as well as in other trees. Whether *Fomes applanatus* Fries. is more important or less important than *Armillaria mellea* as a cause of heart rot or butt rot in aspen is a matter of conjecture. Meinecke[4] considers *Fomes applanatus* second in importance to *Fomes igniarius*. He also found that in Utah *Fomes applanatus* seems to be confined to the butt of the tree, and therefore rarely becomes economically important, tho it may be locally destructive. On the other hand, Eklund and Wennmark[5] find *Armillaria mellea* to be the cause of an important heartrot and butt rot of *Populus tremula* in Sweden.

There is reason to believe that *Fomes igniarius* is responsible for most of the loss due to decay of aspen in Minnesota. In the course of this study, no fruiting bodies of *Fomes applanatus* were found, and only in two instances were fruiting bodies of *Armillaria mellea* found. In both of these cases the two affected trees also bore numerous fruiting bodies of *Fomes igniarius*. The comparatively rare occurrence of sporophores of *Fomes applanatus* and *Armillaria mellea* does not necessarily mean that they do not cause considerable decay in aspen.

Minnesota is not unlike many other regions with respect to the damage caused to aspen by *Fomes igniarius*. For example, Cameron[6] found that around Lesser Slave Lake, in Canada, at least 50 per cent of the aspen is without commercial value, owing to attacks of *Fomes igniarius*. Von Schrenk and Spaulding[7] likewise point out that in New England, as well as in Colorado and New Mexico, it is almost impossible to find healthy stands of aspen which have attained any appreciable age because of the extreme destruction brought about by this fungus.

For practical purposes then, *Fomes igniarius* may be regarded as the primary cause of heartrot of aspen in Minnesota. This is done, fully recognizing the fact that other fungi may be of greater importance in this connection than we have been able to determine in this study.

[4] Meinecke, E. P. Pathology of quaking aspen in relation to the management of the species in District 4. Unpublished manuscript.

[5] Eklund, S. and Wennmark, G. Några undersokninger av aspskog. Skogsvards Föreningens Tidskrift. 23:80-104. 1925.

[6] Cameron, D. R. Report on timber conditions around Lesser Slave Lake. Forestry Branch Bull 29. Ottawa, Canada. 1912.

[7] Schrenk, H. von and Spaulding, P. Diseases of deciduous forest trees. U. S. Dept. of Agr., Bur. Plant Indust., Bull. 149. 1909.

FIELD METHODS

That the results obtained from this study might be generally applicable to the entire aspen region, the sample plots for obtaining cull data were distributed throughout the commercial range of the tree in the state. Aspen occurs generally throughout the entire northern half of the state with the possible exception of the Red River Valley. Even there, aspen is one of the most common of forest trees, but nowhere in this particular region is it found in large quantities or in comparatively large sizes.

The results obtained in this study are based upon data from 385 sample trees selected from 77 sample plots one-tenth acre to one acre in area. About half of these plots were selected in fully-stocked stands, the rest in stands not fully stocked. The trees in fully-stocked stands from which the pathological data were obtained, were trees of average volume for the stand in question. The sample plots were distributed about equally in well stocked and understocked stands, because in all probability well stocked stands have never been touched by fire. Even a light ground fire causes considerable damage to aspen, killing many of the trees and causing numerous fire scars on many of those remaining. In general, fire scars are one of the most dangerous avenues of entrance for wood-destroying fungi.

No data are available to show the extent on an area basis to which present stands of aspen have been damaged by fire, but it is undoubtedly appreciable. It should be borne in mind, however, that not all of the understocked sample plots studied were understocked as a result of fire. In some cases the understocking was undoubtedly the result of poor sprouting or seeding or other factors.

On the average five sample trees were cut on each sample plot. As a rule, 3 of these were in the dominant crown class and one each in the intermediate and suppressed crown classes. This general procedure was not always strictly adhered to, as it was very difficult to recognize the different crown classes in both very young and old stands.

The sample trees were cut with a 1-foot stump and then further cut into 8-foot sections up to a 3-inch top. Whenever possible the age was determined on the stump. It was sometimes impossible to determine the age on the stump, on account of an advanced stage of decay. In these cases either the average age of the plot was taken, that is, the age of the other trees in question, or else the age was determined at the end of the first 8-foot section by adding five years to the age thus obtained.

The following data were taken on each sample plot on which sample trees were cut and studied:

- Location of plot
- Average age of trees on plot
- Site quality
- Associated species
- Character of soil
- Ground cover
- Brush
- Evidence of
 - Fires
 - Grazing
- Crown density
- Number of trees per plot
- Diameter breast high
- Total heights

The following data were obtained from each sample tree:

- Diameter breast high outside bark (to nearest 1/10 inch)
- Total height (to nearest foot)
- Age on stump
- Crown class
- Wounds
 - Mechanical
 - Fire
 - Insect
- Presence and number of sporophores
- External signs of decay
 - Persistent dead branches
 - Color of bark
 - Character of branch scars
 - Early production of furrowed bark
- Apparent avenue and height of infection
 - Branch scars
 - Insect scars
 - Fire scars
 - Root
- Causal organism

In Minnesota, it is the exceptional aspen tree that does not have a discolored heart. The intensity of the discoloration varies between wide limits and in general probably corresponds to different stages of decay. This coloration is not necessarily, however, always associated with decay and may be the result of either mechanical or insect injury.

In this study three stages of decay were arbitrarily distinguished—incipient, intermediate, and final. In incipient decay the wood is faintly colored from light pink to straw brown. The intermediate stage includes all degrees of coloration from straw to chocolate brown, but the wood is apparently still hard and firm. The final stage includes all soft, punky wood irrespective of color. The classification was limited to these three stages in order to allow an approximate determination of cull for certain industries utilizing aspen. For example, the excelsior industry apparently accepts and utilizes all sound, firm wood irrespective of color. The pulp and paper industry accepts, as far as we were able to determine, wood having even a fairly dark color, but does not want wood having a low specific gravity. The box-shook industry apparently discriminates against the dark wood in scaling, even tho it may appear to be still quite hard and firm. If a match industry utilizing aspen wood is ever developed in Minnesota, it is not unlikely that even slight discolorations might be considered as cull. However, the practice of culling varies greatly even in the same industry. The above statements indicate the apparent trend of culling in the various industries utilizing aspen.

In order to determine the cull based on different stages of decay the following data were obtained from each sample tree:

Diameter of total rot at stump to nearest 1/10 inch

Diameter of total rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

Diameter of final and intermediate rot at stump to nearest 1/10 inch

Diameter of final and intermediate rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

Diameter of final rot at stump to nearest 1/10 inch

Diameter of final rot at sections 1, 2, 3, 4, etc., to nearest 1/10 inch

In all cases the diameter recorded is the average of two diameters taken at right angles to each other, one being the maximum diameter of the decayed core. In cases where a certain stage of rot was evident at one end of an 8-foot section but not at the other end, the 8-foot section was again cut at the center and the rot measurements were also taken at this point. When a certain stage of rot was evident at one end of such a 4-foot section but not on the other end, it was arbitrarily assumed that the rot extended half way through the 4-foot section. In these cases the volume of decay was figured as a cylinder having a uniform diameter equal to that shown on the exposed face.

As aspen usually reproduces by suckers instead of by seeds, it seemed possible that the common avenue of infection might be through the parent root. To determine the possibility of this type of infection, the roots of a considerable number of dominant trees were dug and the limits of decay determined.

METHOD OF COMPILATION

All volumes were computed inside the bark in cubic feet. The stump was considered as a cylinder with a diameter of the stump cut. All stumps were cut one foot high. The volume of each section was determined by means of Smalian's formula.[8] The volume of the tops was considered as a cone. Both total and merchantable volumes were computed. The merchantable volume was determined from the stump to a 3-inch top diameter inside the bark. The volume of each stage of rot was also determined by the use of Smalian's formula.

It was apparent that decay had so decreased the actual sound wood content of many logs and trees that in actual practice the entire log or tree would have been culled. This study, however, concerns itself only with net or actual cull. As the degree of utilization of practically all forest trees is rapidly changing, there seems to be little advantage in estimating or trying to estimate gross cull.

If a very large number of measurements had been made, the raw averages of the different stages of rot and tree volume would have approached a fairly smooth, continuous curve. The cost of collecting and computing such a large number would be prohibitive. To approximate the results of such a large sample with the least expenditure of time and money, graphic methods were used, which iron out chance fluctuations of the data due to the size of the sample and errors of observation and also permit interpolation to uniform intervals of the independent variable and therefore facilitate comparisons and interpretations.

The volume of total rot, final plus intermediate rot, final rot, peeled total, and merchantable volume were computed for each tree. The trees were then grouped in 10-year age classes (11-20, 21-30) and each of the above items was averaged. The volumes of incipient and intermediate rot were obtained from the averages for each age class by deducting the volume of the intermediate and final rot from the total volume of rot. Each stage of rot was expressed as a percentage of the total rot and also as a percentage of the tree volume.

In order to eliminate widely discordant values, affecting materially the averages, the following procedure was used: A preliminary volume on age curve was drawn among the raw averages so that the sum of the deviations above the curve were approximately equal to those below and so the sum of the raw data and the sum of the values read from the curves checked within 1.5 per cent. An attempt to keep the sum of

[8] Volume in cubic feet $= \left(\frac{b_1+b_2}{2}\right)L$, where b_1 and b_2 are the end areas in square feet and L the length of the section in feet.

the deviations[9] of the actual tree volumes from the curve as small a possible was also made by drawing the curve nearest to the points o greatest weights.

The volume in cubic feet corresponding to the actual age of eac tree was read from this curve and the percentage of deviation from th curved value was computed. These deviations in the form of a fre quency curve are shown in Figure 1.

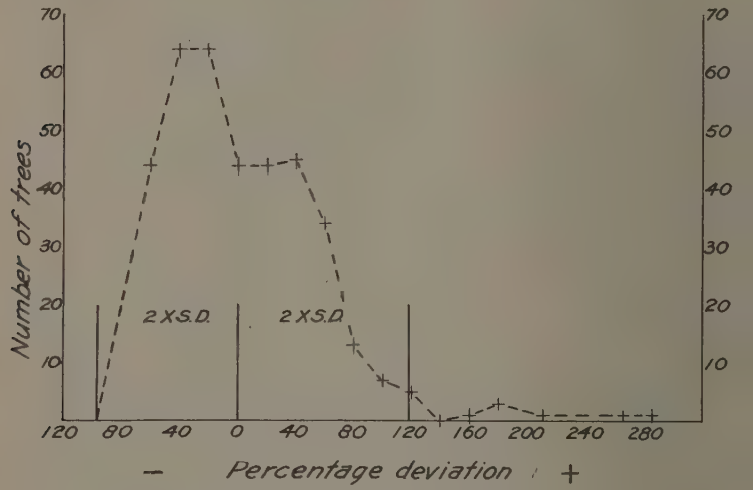


Fig. 1. Frequency Distribution of Percentage Deviations from the Total Peeled Volume Curv Rejection limits equal to twice the standard deviation (S.D.)

The average deviation above and below the curve was compute and found to be +47 per cent and —38 per cent. This wide range i due chiefly to the variation of growing conditions or site represente by the sample. These percentages and the curve of deviations sho a positive skewness and for this reason the limit of rejection is greate for the values above the curve than for those below. The factor 1.25 of the normal curve of error, was used for computing the standar deviation from the average deviation. The standard deviation abov the curve is 47 per cent × 1.253, or 59 per cent; and below, 38 pe cent × 1.253, or 48 per cent. Twice the standard deviation, or +11 per cent and —96 per cent, was arbitrarily taken as the limit of rejec tion. On this basis, the nine trees noted in Table I were eligible fo rejection, but were thoroly examined for mistakes in computing th original data or other causes that might be the reason for the wid deviation before they were finally discarded.

[9] Theoretically, according to the theory of least squares, as the name implies, the su of the deviations squared should be a minimum.

TABLE I

REJECTED TREES HAVING A PERCENTAGE DEVIATION OF OVER TWICE THE STANDARD DEVIATION

Age, years	Deviation percentage	No. of trees
29	+268	1
30	+287	1
32	+150	1
35	+125	1
37	+174	1
41	+219	1
44	+124	1
50	+172	1
51	+188	1

It is quite evident from the deviation percentages and the frequency curve that these rejections are entirely justified. It is especially necessary to eliminate these trees, as there are no compensating values of opposite sign.

It probably would have been desirable to use total rot as an additional basis for rejection. This would have eliminated a few trees for which the total rot varied considerably from the curve.

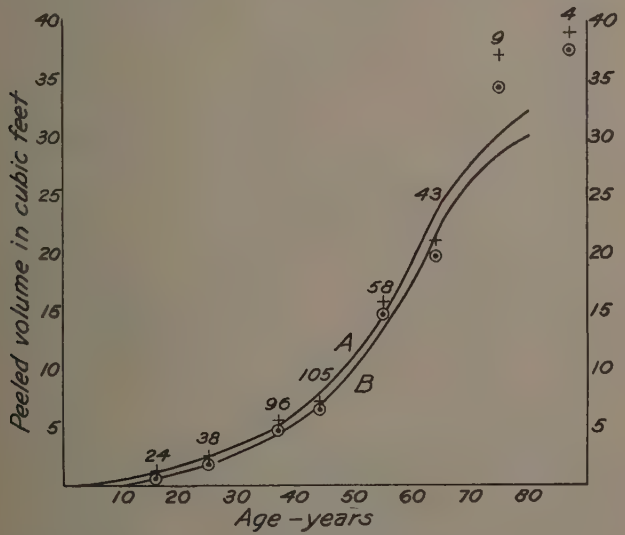


Fig. 2. Peeled Volume in Cubic Feet of Average Tree by Age Classes

A. Total volume including stump, stem, and top

B. Merchantable volume above a 1-foot stump to a top diameter inside of bark of 3 inches

The actual average volumes in cubic feet for each stage of rot—intermediate, final, and total—and peeled volume of trees, and also the percentage of total rot and tree volume, were plotted on age to determine which values showed the most consistent and well defined curves. Examination of these plotted raw averages (similar to Figs. 2, 3, 4,

and 5) showed that the actual volumes in cubic feet for the great portion of the curve and the percentages of the volume showed the lea tendency to deviate from a smooth curve. For this reason the actu volumes in cubic feet and the percentages of tree volume were used obtain the first approximation of the final values. Smooth curves we drawn independently of each other through the raw averages for peel tree volume, total rot, each stage of rot, and also the latter as percentag of tree volume, and balanced to make the sum of the deviations abo the curve approximately equal to the sum of those below. The valu

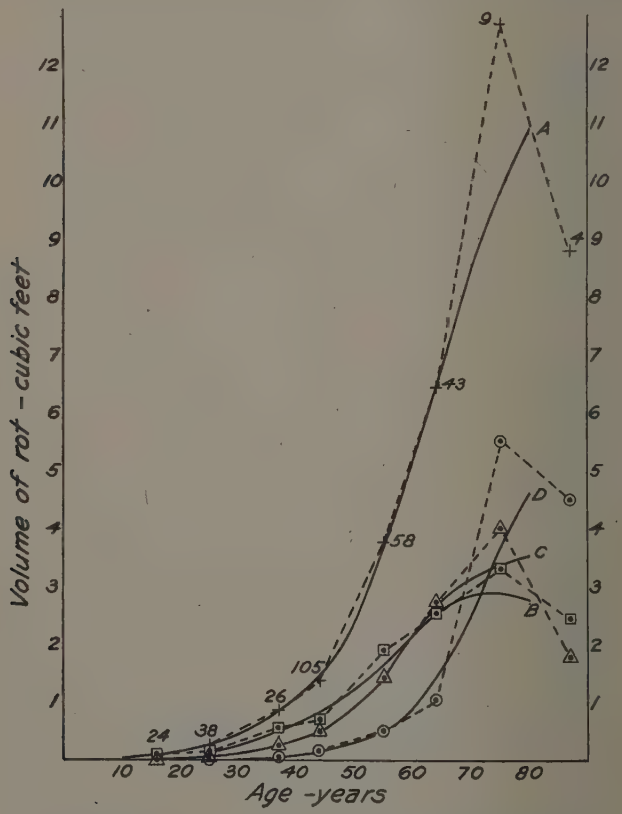


Fig. 3. Volume of Rot in Cubic Feet in Entire Stem of Aspen Trees
A Total rot
B Incipient
C Intermediate
D Final

for even 10-year periods were read from these curves and a comput value of total peeled tree volume was obtained by dividing the curv volume of rot in cubic feet by the corresponding curved values of r as a percentage of tree volume. This was done for each stage of r including the sum of intermediate and final rot and the total rot.

was also necessary to make the sum of the curved values for the different stages of rot equal the curved total rot. Each series of computed tree volumes was plotted among the original averages to check both trend and balance of the curve. If they did not check, the percentage and cubic volume curves were adjusted until all the curves conformed to the raw averages, cross-checked, and balanced. Any inconsistency in trend in any one curve, especially where the data were scant, showed up in this method of cross-checking. This procedure resulted in five series of computed values for the total peeled volume of the tree and one series of values obtained by curving the raw data in cubic feet. These figures were then averaged by 10-year age classes to obtain the

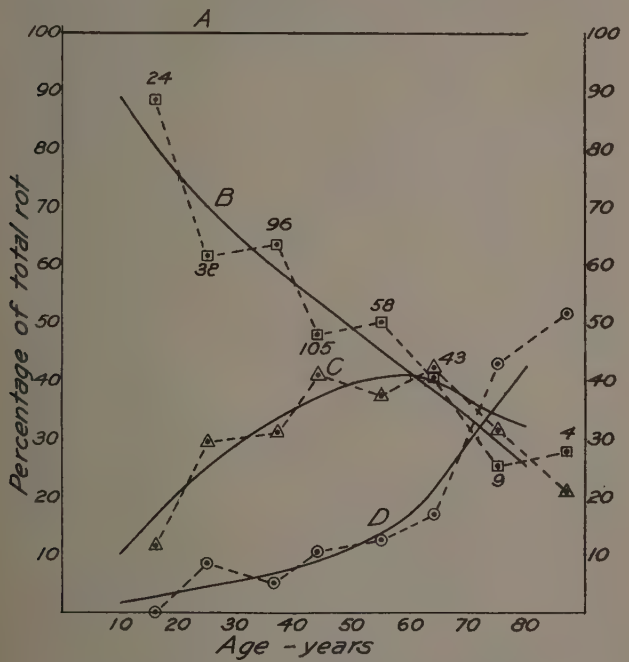


Fig. 4. Volume of Each Stage of Rot as a Percentage of Total Rot in Entire Stem
A Total rot
B Incipient rot
C Intermediate rot
D Final rot

second approximate curve for total tree volume. Additional cross-checks on the trend were made by substituting each factor in terms of each other in the above relation to compute tree volume. After a little adjusting, a position for each curve was found, to alter which, would mean radically changing other values. Such a condition probably represents the most probable value of the variables for a given sample obtained through free-hand curving.

In the above check very little attention or none was paid to each stage of rot as a percentage of total rot. The percentages computed from the cubic foot values obtained above should follow the trend of these averages and also balance among them. The percentages computed from the curved values obtained by the above procedure were used as first approximations in this series of curves; and the same procedure, discussed above, was employed in cross-checking. In this case the total rot was computed from each stage of rot in cubic feet and the corresponding percentage of total rot, and then averaged to obtain the final total rot. In adjusting these curves, a slight departure from the trend of the raw averages was made in the percentage curve of in-

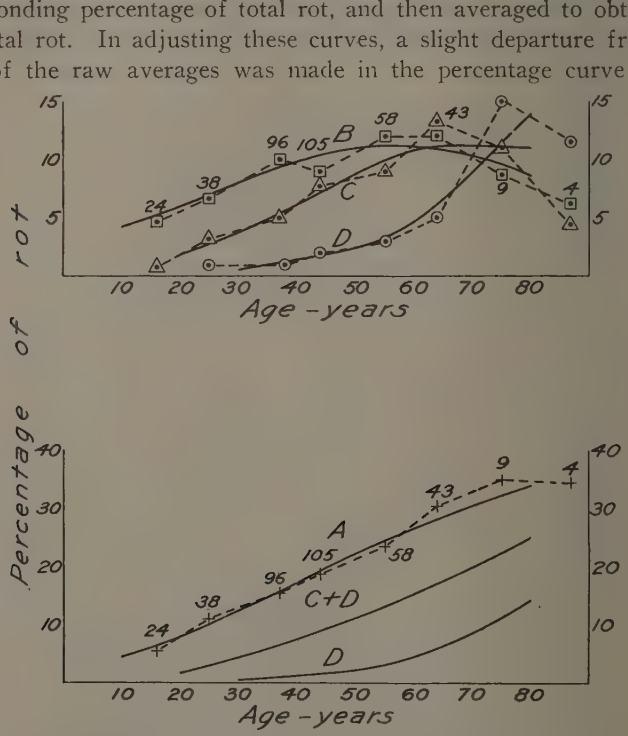


Fig. 5. Rot as a Percentage of Total Tree Volume

A Total rot
B Incipient
C Intermediate
D Final
C+D Intermediate and Final

cipient rot between 50 and 70 years. To follow the original data between these ages, it would be necessary to have the curve of incipient rot as a percentage of total increase and then decrease. This deviation was considered a matter of chance and was therefore partially ironed out, but not without throwing some of the other curves slightly out of balance and trend. The whole system was given a final cross-check which resulted in further slight readjustments, resulting in the final curves presented in these figures.

The merchantable values were then expressed as a percentage of the corresponding total figures and curved. The curved values for the entire stem were multiplied by these curved percentages to obtain the final merchantable data. As these percentages formed well defined curves, no difficulty was experienced in adjusting them. Rough checks indicate that they conform to the original data as well as to the final figures on total volume.

Any secondary data, especially when compiled by freehand graphic methods, should be checked against the original values. In the theory of least squares these checks are inherent in the method. The arithmetical mean of the curved data for the entire sample should be equal to the mean of the original sample, or, in other words, the sum of the original data should be equal to the sum of the curved values read for each individual observation. Table II gives a comparison of the totals and averages of the original and curved data, and the percentage of error based on the curved values. The curves could be still further adjusted by these small percentages to make the errors negligible.

TABLE II
AGGREGATE CHECK OF RAW AND CURVED DATA

Item	Total volume			Mean	
	Original data	Curved data	Percentage error	Original data	Curved data
	cu. ft.	cu. ft.		cu. ft.	cu. ft.
Total peeled volume	3947	3992	1.2	10.25	10.37
Total rot in entire stem	973	985	1.1	2.53	2.56
Incipient rot	398	399	0.3	1.34	1.36
Intermediate rot	368	366	0.6	0.96	0.95
Final rot	211	212	0.5	0.55	0.55

For the same sample of data, that method of compilation, according to the theory of least squares, gives the best representative values which makes the sum of the deviations squared the least possible. Where freehand methods of curving are used, Bruce[10] has recommended that the sum of the deviations be used instead, because of the amount of work involved in computing the squares. If the sum of the deviations is as small as possible, the average deviation will be also. In this study the average deviations were computed only for total tree volume and total volume of rot, in cubic feet, and are as follows:

Total volume of tree ± 42 per cent (before rejection)
Total volume of rot ± 54 per cent (after rejection)

These values are given in order that they may be compared with those obtained in similar studies which may be undertaken in the future.

The average deviation also represents the degree of scatter of the individual tree values around the curve and in that way indicates the

[10] Bruce, D. A proposed standardization of the checking of volume tables. Jour. For. 18:544-548. 1920.

confidence that can be placed in a prediction by use of the curve. It i readily seen that, with variations on the average of as much as 50 pe cent of the curved value, predictions for individual trees or stands ar useless. The curves, however, are not presented here for that purpos but merely to indicate average conditions.

The variation could have been greatly reduced if separate curve had been prepared for each site. The data available, however, wer insufficient for this.

DECAY OF ASPEN IN RELATION TO AGE

The field data obtained from 385 sample trees were computed o the basis of both total and merchantable volume. Total volume includ the stump, bole, and top without bark; and merchantable volume th bole without the bark above a one-foot stump to a top diameter of inches inside of bark. In Table III are found the raw data which sho the relation between the volume of rot and the age of the stand, base on both the total and the merchantable volume of the tree.

In order to smooth off the results, the data shown in Table III wer plotted and curves drawn by employing the methods previously d scribed. In Figure 2 the average peeled total and merchantable volun in cubic feet are plotted on age.

The volume of total rot for the various age classes was obtaine from Curve A, Figure 3. The volume of each stage of rot as a pe centage of total rot was read from the curves in Figure 4. These pe centages were then applied to the volume of total rot resulting in th values presented in Table IV. These values are plotted in Figure Curves B, C, and D.

The percentages given in Table V and plotted in Figure 5 were ob tained by dividing the curved rot volumes in cubic feet by the curve tree volumes in cubic feet.

TABLE 111

ROT STAGES IN ASPEN BY AGE CLASSES

Minnesota

(Basic data)

Age class	Age	Average		Stage of rot												Basis
				Intermediate and final				Final				Total				
		Peeled vol. of tree		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		
		Total*	Merchantable†	Vol. of rot	% of total vol.	Vol. of rot	% of merchantable vol.	Vol. of rot	% of total vol.	Vol. of rot	% of merchantable vol.	Vol. of rot	% of total vol.	Vol. of rot	% of merchantable vol.	
years	years	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		Trees
11- 20	16	1.10	0.50	0.01	0.9	...	...	...	...	...	...	0.06	5.5	0.05	10.0	24
21- 30	25	2.39	1.70	0.10	4.2	0.08	4.7	0.02	0.8	0.02	1.2	0.27	11.3	0.24	14.1	38
31- 40	37	5.59	4.82	0.32	5.7	0.28	5.8	0.05	0.9	0.04	0.8	0.88	15.7	0.84	17.4	96
41- 50	44	7.31	6.52	0.72	9.9	0.68	10.4	0.15	2.0	0.14	2.1	1.38	18.9	1.34	20.5	105
51- 60	55	15.84	14.84	1.88	11.9	1.78	12.0	0.47	3.0	0.44	2.9	3.78	23.8	3.64	24.5	58
61- 70	64	21.10	19.61	3.83	18.2	3.62	18.5	1.08	5.1	0.99	5.0	6.41	30.4	6.15	31.4	43
71- 80	75	36.63	34.22	9.54	26.0	9.03	26.4	5.49	15.0	5.24	15.3	12.77	34.8	8.33	35.7	9
81- 90	87	39.03	37.37	6.36	16.3	5.93	15.9	4.54	11.6	4.21	11.3	8.80	22.5	3.88	22.3	4
91-100	97	23.51	22.09	10.67	45.4	10.34	46.8	5.08	21.6	4.94	22.4	10.81	46.0	10.48	47.4	4
101-110	103	29.82	27.40	10.63	35.6	10.33	37.7	7.16	24.0	7.06	25.8	11.14	37.3	10.86	39.6	4
Total																385

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes volume of peeled stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

TABLE IV

VOLUME OF ROT IN ASPEN TREES

Minnesota

Age	Stage of rot																			
	Incipient				Intermediate				Final				Intermediate and final				Total			
	Total vol.*		Merchantable vol.†		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.		Total vol.		Merchantable vol.	
	Vol. of rot	% of total rot	Vo.. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total rot	Vol. of rot	% of merchantable rot	Vol. of rot	% of total tree vol.	Vol. of rot	% of merchantable vol.
Yr.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
10	0.02	88.8	...	...	...	10.1	...	...	...	...	...	...	...	...	...	...	0.02	4.4	...	...
20	0.10	75.5	0.09	81.8	0.03	20.9	0.02	18.2	...	3.6	...	...	0.03	24.5	0.02	18.2	0.13	8.1	0.11	11.5
30	0.28	65.5	0.27	67.5	0.13	29.1	0.11	27.5	0.02	5.4	0.02	5.0	0.15	34.5	0.13	32.5	0.43	12.5	0.40	14.8
40	0.61	56.7	0.60	58.8	0.38	35.5	0.35	34.3	0.08	7.8	0.07	6.9	0.46	43.3	0.42	41.2	1.07	17.4	1.02	18.9
50	1.20	49.3	1.18	50.4	0.97	39.6	0.92	39.3	0.27	11.1	0.24	10.3	1.24	50.7	1.16	49.6	2.44	22.1	2.34	23.0
60	2.18	41.8	2.14	42.8	2.13	41.0	2.03	40.6	0.90	17.2	0.83	16.6	3.03	58.2	2.86	57.2	5.21	26.8	5.00	27.5
70	2.85	33.6	2.80	34.4	3.13	36.8	2.98	36.5	2.51	29.6	2.37	29.1	5.64	66.4	5.35	65.6	8.49	30.4	8.15	31.2
80	2.78	25.6	2.74	26.2	3.51	32.2	3.34	32.0	4.59	42.2	4.36	41.8	8.10	74.4	7.70	73.8	10.88	33.8	10.44	34.6

* Total volume includes stump, stem, and top without bark. The values of rot under total volume were compiled by multiplying the total rot figures by the curved percentages for each stage of rot.

† Merchantable volume includes peeled volume of stem above a 1-foot stump to a top diameter of 3 inches inside bark.

TABLE V
ROT AS A PERCENTAGE OF TREE VOLUME OF ASPEN
Minnesota

Age	Stage of rot										Peeled volume of tree	
	Incipient		Intermediate		Final		Intermediate and final		Total rot			
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable	Total	Merchantable	Total	Merchantable
Yr.	%	%	%	%	%	%	%	%	%	%	cu. ft.	cu. ft.
10	4.4	...	...	...	...	...	...	...	4.4	...	0.45	...
20	6.2	9.3	1.9	2.1	...	...	1.9	2.1	8.1	11.5	1.60	0.97
30	8.1	10.0	3.8	4.1	0.6	0.7	4.4	4.8	12.5	14.8	3.45	2.71
40	9.9	11.1	6.2	6.5	1.3	1.3	7.5	7.8	17.4	18.9	6.15	5.41
50	10.8	11.6	8.8	9.0	2.4	2.4	11.2	11.4	22.1	23.0	11.05	10.18
60	11.2	11.8	11.0	11.1	4.6	4.6	15.6	15.7	26.8	27.5	19.45	18.20
70	10.2	10.7	11.2	11.4	9.0	9.1	20.2	20.5	30.4	31.2	27.90	26.15
80	8.6	9.1	10.9	11.1	14.3	14.4	25.2	25.5	33.8	34.6	32.20	30.19

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes the peeled volume of the stem above a 1-foot stump to a top diameter of 3 inches inside bark.

In Table VI are given the gross and net volume of aspen at different ages. The net volume tables were obtained by deducting the volume of the various stages of rot from the tree volume.

TABLE VI
GROSS AND NET VOLUME OF ASPEN TREES
Minnesota

Age	Peeled volume of tree							
	Gross volume		Net volume (deducting)					
			Final rot		Intermediate and final		Total rot	
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
10	0.45	...	0.45	...	0.45	...	0.43	...
20	1.60	0.97	1.60	0.97	1.57	0.95	1.47	0.86
30	3.45	2.71	3.43	2.69	3.30	2.58	3.02	2.31
40	6.15	5.41	6.07	5.34	5.69	4.99	5.08	4.39
50	11.05	10.18	10.78	9.94	9.81	9.02	8.61	7.84
60	19.45	18.20	18.55	17.37	16.42	15.34	14.24	13.20
70	27.90	26.15	25.39	23.78	22.26	20.80	19.41	18.00
80	32.20	30.15	27.61	25.79	24.10	22.45	21.32	19.71

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes peeled volume of stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

The periodic annual growth and decay were computed from the data presented in Tables IV and VI and the results are shown in Table VII and Figure 6.

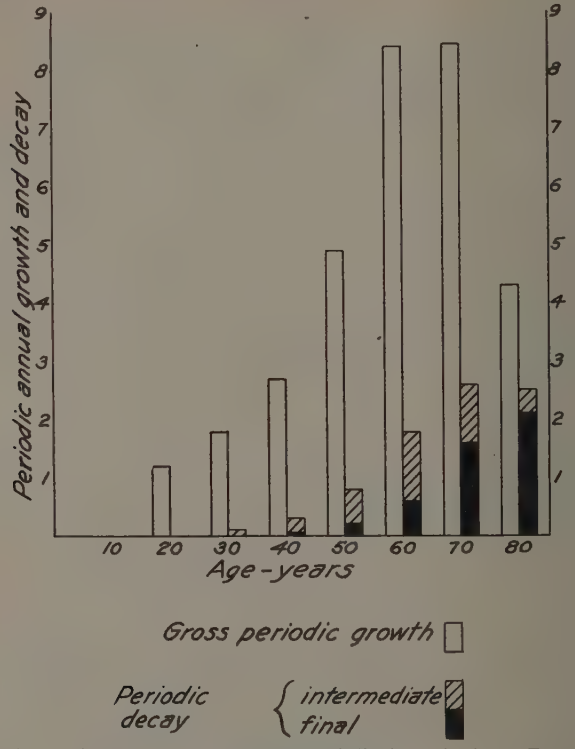


Fig. 6. Gross Periodic Growth and Periodic Decay in Aspen Trees
(in tenths of cubic feet)
Based on total volume of stem excluding bark

The basic data upon which this study is based were obtained from individual sample trees. In order to determine the effect of decay on rotation, it is necessary to use the stand as a basis for the computation rather than the individual tree. The stand is the unit of management the mean annual growth of which culminates long before that of the individual tree. To obtain these stand data, the percentages of rot in the average tree for different age classes were applied to the corresponding yields per acre of well stocked aspen stands on average sites.

The figures for the stand are based on the total yield per acre in cubic feet of all trees one inch in diameter and over, and are taken from unpublished normal yield tables for aspen in Minnesota. The percentages of rot found in the present study were applied directly to these values. This is the sample tree method and for this reason inherits the errors involved in it. The results of these calculations are shown in Table VIII and Figure 7.

TABLE VII

PERIODIC ANNUAL GROWTH AND DECAY IN ASPEN TREES

Minnesota

Age	Periodic annual growth								Periodic annual decay											
	Gross		Net (deducting)						Final rot				Intermediate and final rot				Total rot			
			Final rot		Intermediate and final		Total rot		Total		Merchantable		Total		Merchantable		Total		Merchantable	
	Total*	Merchantable†	Total	Merchantable	Total	Merchantable	Total	Merchantable	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth	Vol.	% of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
10	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
20	0.12	...	0.12	...	0.11	...	0.11	...	...	...	...	...	...	...	...	...	0.01	8.3	...	...
30	.18	0.17	.18	0.17	.17	0.16	.15	0.14	...	...	...	...	0.01	5.6	0.01	5.6	.03	16.7	0.03	16.7
40	.27	.27	.26	.26	.24	.24	.21	.21	0.006	2.2	0.005	1.9	.03	11.1	.03	11.1	.06	22.2	.06	22.2
50	.49	.48	.47	.46	.41	.41	.35	.35	.02	4.1	.02	4.2	.08	16.3	.07	14.3	.14	28.6	.13	26.5
60	.840	.802	.78	.74	.66	.63	.56	.53	.06	7.1	.06	7.5	.18	21.6	.17	21.2	.28	33.3	.27	33.7
70	.845	.80	.68	.65	.58	.55	.52	.48	.16	18.9	.15	18.7	.26	30.8	.25	31.2	.33	39.1	.32	40.0
80	0.43	0.40	0.22	0.20	0.18	0.16	0.19	0.17	0.21	48.8	0.20	50.0	0.25	58.1	0.24	60.0	0.24	55.8	0.23	57.5

* Total volume includes stump, stem, and top without bark.

† Merchantable volume includes the peeled volume of the stem above a 1-foot stump to a top diameter of 3 inches inside of bark.

Double lines show culmination of periodic annual growth.

TABLE VIII
GROSS AND NET YIELD AND VOLUME OF ROT PER ACRE
WELL-STOCKED ASPEN STANDS ON AVERAGE SITES
Minnesota

Age	Total yield per acre*				Volume of rot per acre				
	Gross†	Net (deducting)							
		Final rot	Intermediate and final rot	Total rot	Incipient	Intermediate	Final	Intermediate and final	Total
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.
20	1150	1150	1130	1060	70	20	...	20	90
30	1760	1750	1680	1540	140	70	10	80	220
40	2500	2470	2310	2060	250	160	30	190	440
50	3220	3140	2860	2510	350	280	80	360	710
60	3820	3640	3220	2800	420	420	180	600	1020
70	4290	3900	3420	2990	430	480	390	870	1300
80	4600	3940	3450	3050	400	490	660	1150	1550

* Total yield includes stump, stem, and top without bark of all trees one inch in d.b.h. and over.

† Gross yield figures are values of the 60-foot site index class from the normal yield tables for aspen compiled in 1926 by S. Gevorkiantz.

That these percentages can be applied to an average tree differing in volume from that shown in this study, is indicated by the data presented in Table IX, which show that the percentage of rot for each age class does not vary greatly for trees of different size. The two high values in the table for suppressed trees are based on one tree only and can not, therefore, be considered significant.

TABLE IX
ROT AS A PERCENTAGE OF TOTAL TREE VOLUME BY CROWN CLASSES
(Raw data)

Age	Crown class		
	Dominant	Intermediate	Suppressed
yr.	per cent	per cent	per cent
11-20	6	..	..
21-30	11	11	12
31-40	16	18	17
41-50	19	24	17
51-60	24	24	43*
61-70	30	27	36*
71-80	35	..	..

* One tree only.

These results do not agree with the idea held by some, that rapidly growing thrifty trees resist, or at least limit, the attacks of wood-destroying fungi. Furthermore, they are not in accord with the results of Eklund and Wennmark[11] in their study of *Populus tremula* in Sweden. They claim that vigorous stands are more resistant to stem rot than less vigorous stands. They found, in stands of the same age, that the percentage of total rot decreases rapidly as the growth percentage (after Pressler) increases.

[11] Eklund, S. and Wennmark, G. loc. cit.

Whether or not there is any great variation in the percentage decay in different sized trees of the same age is a very important question and merits a more comprehensive study. If the variation is small, as found in this study, the pathological problem in even aged stands on different sites is greatly simplified and it will be possible to apply pathological data to yield figures for all sites upon which the particular tree species is found in well stocked stands. If, however, further study does not

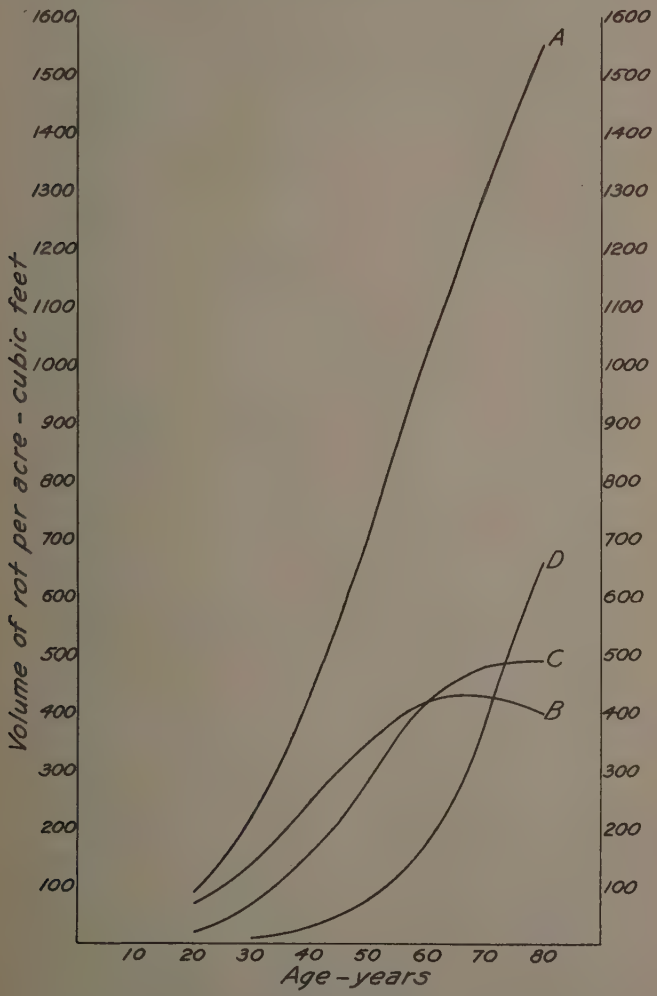


Fig. 7. Volume of Rot per Acre in Well Stocked Aspen Stands on Average Sites. Based on the total yield per acre in cubic feet excluding bark

A Total rot
B Incipient
C Intermediate
D Final

confirm the results here reported, it will be necessary to gather pathological data representative of the different sites.

In Table X are shown the gross and the mean annual growth and decay per acre for well stocked aspen stands on average sites.

The gross mean annual growth and mean annual decay per acre in well stocked aspen stands on average sites are shown in Figure 8.

Curves showing the culmination of gross and net mean annual growth per acre in well stocked stands on average sites are shown in Figure 9.

Gross and net periodic annual growth and decay are shown in Table XI. In Figure 10 are shown the gross periodic annual growth and periodic annual decay per acre in well stocked stands on average sites.

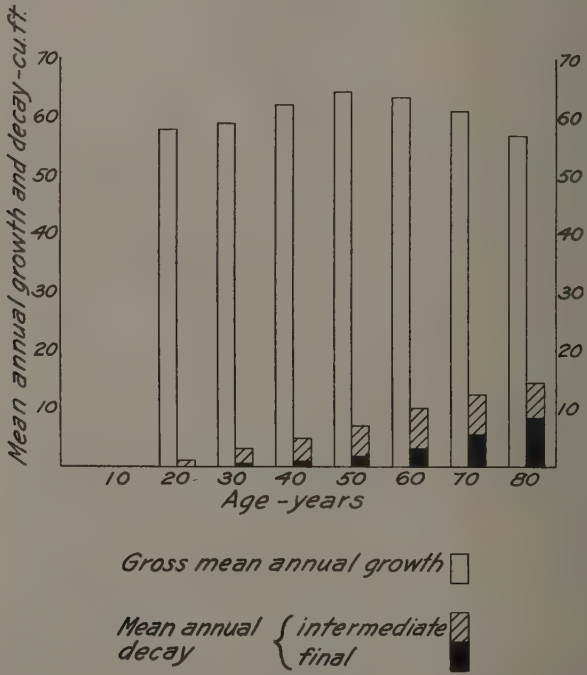


Fig. 8. Gross Mean Annual Growth and Mean Annual Decay per Acre in Well Stocked Aspen Stands on Average Sites
Based on total yield per acre excluding bark

Since incipient decay is ordinarily omitted in figuring cull in aspen for most uses, it is omitted from most of the following discussion. Age classes above 70 years are also omitted, as there is little likelihood that aspen will be grown on rotation over 70 years.

TABLE X

GROSS AND NET MEAN ANNUAL GROWTH AND DECAY PER ACRE. WELL STOCKED ASPEN STANDS ON AVERAGE SITES*
Minnesota

Age	Mean annual growth per acre				Mean annual decay per acre									
		Net (deducting)			Incipient		Intermediate		Final		Intermediate and final		Total rot	
	Gross	Final	Intermediate and final	Total rot	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
20	58	58	56	53	3.5	6.0	1.0	1.7	...	...	1.0	1.7	4.5	7.7
30	59	58	56	51	4.7	8.0	2.3	3.9	0.3	0.5	2.6	4.4	7.3	12.4
40	62	62	58	51	6.2	10.0	4.0	6.4	0.8	1.3	4.8	7.7	11.0	17.7
50	64.4	63	57	50	7.0	10.8	5.6	8.7	1.6	2.5	7.2	11.2	14.2	22.0
60	63.7	61	54	47	7.0	11.0	7.0	11.0	3.0	4.7	10.0	15.7	17.0	26.7
70	61	56	49	43	6.1	10.0	6.9	11.3	5.6	9.2	12.5	20.5	18.6	30.5
80	57	49	43	38	5.0	8.8	6.1	10.7	8.3	14.6	14.4	25.3	19.4	34.1

* Based on a yield including the stump, stem, and top without bark of all trees 1 inch d.b.h. and up.
Double lines show culmination of periodic annual growth.

TABLE XI

GROSS AND NET PERIODIC ANNUAL GROWTH AND DECAY. WELL STOCKED ASPEN STANDS ON AVERAGE SITES

Minnesota

Age	Periodic annual growth per acre*				Periodic annual decay per acre									
		Net (deducting)			Incipient		Intermediate		Final		Intermediate and final		Total rot	
	Gross	Final	Intermediate and final	Total rot	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth	Volume	Percentage of gross growth
yr.	cu. ft.	cu. ft.	cu. ft.	cu. ft.	cu. ft.		cu. ft.		cu. ft.		cu. ft.		cu. ft.	
20	..	..	..	..	...	...	..	...	..	...	..	...	..	...
30	61	60	55	48	7	11.5	5	8.2	1	1.6	6	9.8	13	21.3
40	74	72	63	52	11	14.9	9	12.2	2	2.7	11	14.9	22	29.8
50	72	67	55	45	10	13.9	12	16.7	5	6.9	17	23.6	27	37.5
60	60	50	36	29	7	11.7	14	23.3	10	16.7	24	40.0	31	51.7
70	47	26	20	19	1	2.1	6	12.8	21	44.7	27	57.5	28	59.6
80	31	4	3	6	3†	9.7†	1	3.2	27	87.1	28	90.3	25	80.6

* Based on a ten-year period and on a yield including the stump, stem, and top without bark of all trees one inch in d.b.h. and over.

† Decrease.

Double lines show culmination of periodic annual growth.

At 70 years, 20.2 per cent of the total volume of the tree is in intermediate and final stages of rot; at 60 years, 15.6 per cent; at 50 years, 11.2 per cent, and at 40 years, 7.5 per cent. If the intermediate stage of decay is disregarded and only the final stage of rot is culled, then at 70 years the total volume of the tree is reduced 9.0 per cent; at 60 years, 4.6 per cent; at 50 years, 2.4 per cent, and at 40 years, 1.3 per cent.

On the basis of merchantable volume, the values are quite similar. For example, at 70 years the final rot and intermediate stage of decay account for 20.5 per cent of the merchantable volume; at 60 years, 15.7 per cent; at 50 years, 11.4 per cent; and at 40 years, 7.8 per cent. If only the final stage of decay is considered, it is evident that the merchantable volume is reduced 9.1 per cent at 70 years, 4.6 per cent at 60 years, 2.4 per cent at 50 years, and 1.3 per cent at 40 years.

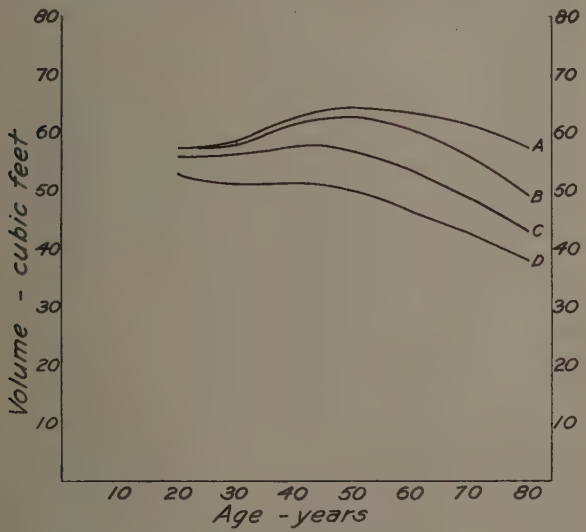


Fig. 9. Culmination of Gross and Net Mean Annual Growth per Acre in Well-Stocked Aspen Stands on Average Sites

A Gross mean annual growth
B Net growth, deducting final rot
C Net growth, deducting final and intermediate rot
D Net growth, deducting total rot

These deductions for defects due to decay in aspen will largely depend on the specific use to which the wood is put. A superficial study of the wood requirements of the excelsior industry indicates that small amounts of decay, even of the final stage, do not seriously interfere with the use of aspen for excelsior. Portions of billets showing advanced stages of decay are not actually used, but the comparatively sound wood immediately surrounding the rot apparently is used.

In the box shook industry, brown heartwood, if firm, is ordinarily not considered a serious defect. It must be very difficult, however, to determine when brown heartwood is sound enough for use, as even when apparently firm the annual rings very often separate and the wood checks badly in drying.

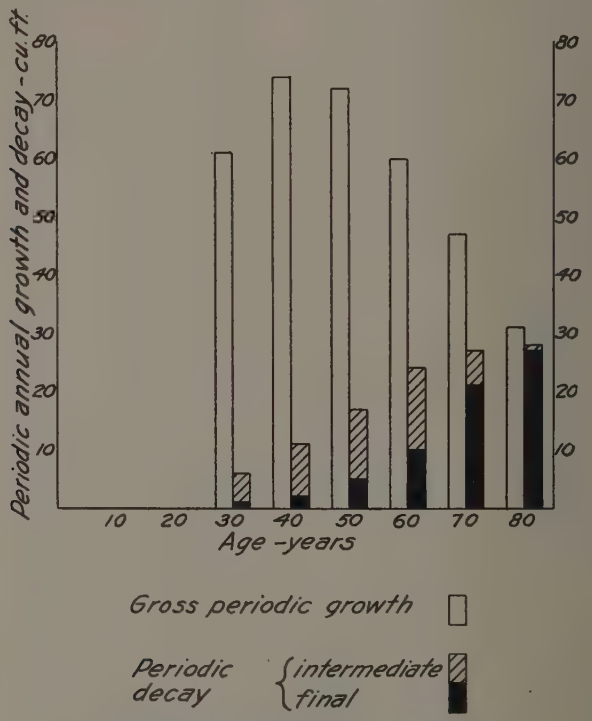


Fig. 10. Gross Periodic Annual Growth and Periodic Annual Decay per Acre in Well-Stocked Aspen Stands on Average Sites
Based on total yield per acre excluding bark

For some boxes a light colored wood has certain advantages, in which case almost any marked coloration is objectionable. From the point of view of this study, final rot should certainly be culled in the box shook industry and the intermediate stage of decay may or may not be considered a defect, depending upon the use to which the box is put.

In the pulp industry, yield of cellulose, color of pulp, and strength of sheet are important considerations. Apparently the pulp industry has not yet determined the exact stage in the deterioration of aspen at which it is no longer profitable or desirable for use, but it is obvious that wood showing even advanced stages of decay is sometimes used. This phase offers interesting problems for further study.

In the use of aspen for rough construction lumber, a slightly darkened color should not be a serious drawback if the mechanical properties of the wood are not seriously affected by the rot. Such wood should not be used in exposed places or in contact with the soil.

The curves showing the different stages of rot as percentages of total rot show that in young trees incipient decay forms a large percentage of the total rot. This percentage, however, decreases rapidly with an increase in age. The intermediate stage of rot is negligible when the trees are very young, but the percentage increases rapidly up to about 60 years and then decreases. The final stage of rot is not evident until the trees reach an age of approximately 30 years, but thereafter it rapidly increases.

A tract of timber managed for the perpetual production of forest products should be so handled that each and every unit or stand is producing at maximum efficiency. In order to obtain the maximum growth for a particular site and a particular species, it is necessary, in addition to proper silvicultural treatment during the life of the stand, to harvest it during the age interval in which the peak of production of a given product occurs. When such mass products are grown as excelsior wood, pulpwood, etc., in which size is not the limiting consideration, the age interval during which the mean annual growth of sound wood culminates makes the most efficient stand. The stand, however, and not the individual tree must be taken as the producing unit, because the average tree continues to grow long after the stand begins to decline, and for this reason its growth culminates later than that of the stand. Our data show that in Minnesota in well stocked aspen stands on average sites, the gross mean annual growth culminates at about 50 years, and when the volume of final and intermediate rot is deducted the growth culminates nearer to 40 years. This seems to indicate, under extensive management, a modified economic rotation of from 40 to 50 years for the production of mass products. When the final rot only is deducted, the mean annual growth culminates at about 50 years.

DECAY OF ASPEN IN RELATION TO INJURIES

Heartrot in aspen in northern Minnesota is so prevalent and widespread that it is the very exceptional tree above 20 years of age that does not show some discoloration of the wood.

From a theoretical point of view, every branch scar is a possible source of infection. It is, however, in most cases impossible to determine the exact mode of entry of the fungus. This is particularly true when the more advanced stages of decay are concerned and when almost every open branch scar is producing a fruiting body of *Fomes igniarius*.

On the older trees from fifteen to twenty fruiting bodies of this fungus on a single tree are not at all uncommon.

Our field observations seemed to show conclusively that fire scars are very important avenues of entrance of *Fomes igniarius*. Seldom was a tree found having a fire scar even a few years old that did not show the final stage of decay. Often very high percentages of cull, especially in the butt log, were associated with fire scars near the ground line. Whether or not these scars were the only or the first means of entry of the fungus could not be determined, but in most cases it seemed probable that they were only accessory means of infection. Large scars permit a considerable volume of sapwood, ordinarily not attacked by heartrot, to dry out partially and decay. It is possible that large fire scars influence the moisture content of the wood for some distance from the scar and at the same time allow freer entry of air, thus making conditions more favorable to rapid decay. Better fire protection will undoubtedly materially reduce the losses from decay in aspen stands.

Insect injuries are also important avenues of entrance of wood-destroying fungi in aspen. Two of the most important and prevalent insects affecting aspen in Minnesota are the aspen borer, *Saperda calcarata* Say., and the carpenter moth, *Prionoxystus rodiniae* Peck. In certain regions both insects seem to be more common than in others. In the vicinity of Itasca Park, deformed trees with dead tops are numerous and have from one to several large scars from which a brownish liquid and frass exudes. The wood beneath these scars is riddled by the larvae and more or less completely decayed by wood-destroying fungi. These decayed areas, especially when near the tops of trees, are often limited both above and below by sound wood, indicating that the fungus entered through the surface scar or the larval mines.

It is not unusual in recent infestations to find that the wood around the larval mines is of an intense yellow color and possesses a strong, rather disagreeable odor. The discolored wood seems to be saturated with water and sometimes "bleeds" profusely when cut. Results obtained in culturing this wood indicate that the coloration may not always be due to the activities of wood-destroying fungi. Sooner or later, however, wood-destroying fungi gain access through these injuries and decay proceeds.

Ants often take possession of these old larval mines and further destroy the wood. Numerous cases were found where the entire center of the tree for a longitudinal distance of five or six feet was almost entirely destroyed, leaving nothing but a thin shell of wood. Above this point the top generally dies and is eventually broken off.

On the Cloquet Forest Experiment Station, a large number of small trees 16 to 18 years old were found to be infested with a borer, probably

Plectrodera scalator Fabr. The borer was always found near the ground line and at times the larval mines extended some distance below the ground line into the roots. The larvae of the flat-headed borer, *Poecilonota cyanipes* Say., were often found in trees infested with the aspen borer. In general, however, the flat-headed borer seems not to cause as much damage as the aspen borer, in Minnesota.

Hofer[12] recommends either the cutting of the brood trees or the painting of the scars with carbolineum as a measure to control the aspen borer. Such steps would not, under present economic conditions, be feasible in Minnesota. Hofer also points out that in Utah trees on dry, rocky slopes appear to be more subject to attack than those on less exposed situations. Along the low, moist creek beds and mountain meadows the attack was not so severe as on the drier slopes. It may well be that the attacks of the aspen borer will be materially reduced in Minnesota when silvicultural methods which tend to maintain a maximum rate of growth are applied to the stands.

ROOT STUDIES

As aspen reproduces largely by means of suckers, the possibility of infection through the mother root needs consideration. After an aspen tree has been cut, the stump decays very rapidly and as heartrot which extends into the stump is prevalent in all the comparatively older age classes, the possibility of spread of heartrot from the decayed stump through the roots to an offspring tree presents an important problem.

In coppice the situation is quite different. Here sprouts may become infected directly from the parent stump, as has been shown by Mattoon[13] and others.[14] In chestnut, Mattoon observed that "the infection mainly due to fungi of various sorts spreads from the parent stump upward and was observed to be most in evidence at the base of the shoot." In the case of suckers, the parent and the offspring trees may be separated by many feet of root system. Aspen may also sprout from the stump, but that this method of reproduction is comparatively unimportant is indicated by the work of Baker,[15] who found that of 6724 sprouts 91 per cent were root suckers, 8 per cent were from the root collar, and 1 per cent from the stump. Baker also found that certain small roots appear to be devoted primarily to reproduction, as they run

[12] Hofer, G. The aspen borer and how to control it. U. S. Dept. Agr. Farmers' Bull. 1154. 1920.

[13] Mattoon, W. R. The origin and early development of chestnut sprouts. Forestry Quarterly 7:34-44. 1909.

[14] Long, W. H. The death of chestnuts and oaks due to *Armillaria mellea*. U. S. Dept. Agr. Bur. Plant Indust. Bull. 89, 1914. Zon, Raphael. Chestnut in Southern Maryland. Bur. Forestry Bull. 53. 1904.

[15] Baker, F. S. Aspen in the Central Rocky Mountain Region. U. S. Dept Agr. Bull. 1291. 1925.

for long distances in the shallower soil layer without much change in diameter or furcation and with practically no feeding rootlets. As a rule, also, the sprouting usually takes place a considerable distance from the stump. Sprouts are frequently found near aspen stumps, but these usually come from roots of distant trees, brought near the surface in crossing the large stump roots.

Weigle and Frothingham[16] found that suckers are not produced from roots covered with 6 inches or more of clay and sod, altho they will develop abundantly if the soil is loose and only 2 inches thick. Suckers are produced only by roots which are near the surface and consequently are very liable to injury by animals or logging operations.

Little is found in the literature concerning the possibility of heartrot spreading from the parent stump through the root to the sucker. In this connection it is important to distinguish clearly between typical heartrots and the rootrots that cause a limited amount of heart or butt rot. Since *Armillaria mellea,* one of the more important fungi causing rot in aspen, is an organism of the latter type, it may well be that this fungus and *Fomes igniarius* spread in quite different ways.

Meinecke[17] recognizes the possibility of trees becoming infected through the roots, but no indication is given as to whether these infections result from injuries to the root or spread from the parent stump. From the data presented, however, it is clear that quite irrespective of how the roots became infected, they are of minor importance in connection with the decay of aspen in Utah.

Eklund and Wennmark,[18] in their study of *Populus tremula* in Sweden, studied in considerable detail the question of root infection and that of fungi spreading from a tree to its suckers through the root system. Their observations dealing with the latter point appear somewhat contradictory.

They found root rots were very common on grazed areas and that the roots on such areas always showed numerous injuries. In every case rots appeared in the wounds and usually the rhizomorphs which are characteristic of *Armillaria mellea* were found. They also found that the fungus does not grow further out from the wound in the root branches, but only spreads toward the tree. In no case was any rot found more than 2½ meters from the tree.

As to *Armillaria* rot spreading from the stump to the suckers, Eklund and Wennmark say in part[19] "The opinion is commonly held

[16] Weigle, W. G. and Frothingham, E. H. The aspens: Their growth and management. U. S. Dept. Agr. Forest Serv. Bull. 93. 1911.

[17] Meinecke, E. P. loc. cit.

[18] Eklund, S. and Wennmark, G. loc. cit.

[19] The writers are indebted to Dr. Gunnar Nilsson-Lissner for this translation of Eklund and Wennmark's work.

by foresters that the rot spreads from the stump to the suckers. In order to clear up this question, we blew up a large number of stumps in an area cut over about six years ago, now bearing a dense stand of aspen suckers. The root branches of the old stumps could thus very easily be followed out to the suckers. An inspection of these small trunks showed them to be infected by decay as early as about 6 years of age. The rot followed upward as well as downward in the trunk and seemed to be more prevalent in the stump itself. The old connection between the mother tree and sucker, however, *was completely healthy.*[20] No positive opinion can be expressed as to the nature of this rot as all attempts to cultivate the fungus in a culture have failed. It is impossible that *Fomes igniarius* has already entered through wounds or dry broken branches at this age."

"It is rather interesting to compare these results with the results obtained from Plot 3. In the latter case the trees came from suckers after cutting about 25 years previously. Seventy per cent of the trunks showed heartrot with a diameter of one to three centimeters in the stump cut. These stumps were blasted out and the spreading of the rot and the connections between adjacent trees observed. The fungus had evidently grown from one tree over the other. It was impossible to trace out exactly how the rot got into the trees on this plot. It is not very probable that it entered through wounds on the roots caused by cattle since no injuries worth mentioning could be found. *We, however, consider the best explanation to be that the rot spread from the old stump to the suckers. After a certain number of years the old stump trunk is completely decayed and the root branches also become infected to such an extent that the rot works its way through the connecting root branches and at last reaches the now fairly well developed trees.* This assumption also throws light on the fact that on the five to six year old suckers inspected the young trunks were diseased but the old root branches were healthy." In view of the fact that Eklund and Wennmark found the connection on 5- to 6-year-old suckers and the roots to be perfectly healthy and as no positive evidence was found on Plot 3 that the decay entered the 25-year-old suckers from the roots, the conclusion that the decay entered through the parent root seems hardly warranted. How the interpretation of the facts found on Plot 3 throws any light on the fact that the 5- to 6-year-old suckers were diseased but the old root connection healthy, is not clear.

It is important to note that the above discussion refers to root rot caused by *Armillaria mellea.* Eklund and Wennmark found the case of *Fomes igniarius* quite different. Here, as a rule, the disease seems

[20] The italics in this case are ours.

to be checked in the stump, but in several instances it was found passing out into some of the larger root branches for a distance not exceeding a half meter from the stump, beyond which healthy wood was found to occur.

During the course of the field work in connection with the study of the decay of aspen in Minnesota, more than thirty stumps were dug and the roots carefully examined in order to determine how far the decay extended into the root system. In all but three cases discolorations of any consequence did not extend into the root system for a greater distance than six inches and in by far the greatest number of cases the decay actually terminated in the base of the stump.

In one of the three exceptions mentioned above, the decay in the root was undoubtedly caused by *Armillaria mellea*, as numerous rhizomorphs were found adhering to this root. In this particular case the root had been injured, about 20 years previously, and had not entirely healed. Nevertheless the decayed core in the root was not over an inch in diameter and did not extend outward more than 4 inches beyond the injury.

In the two other exceptions mentioned, the rot extended out 8 to 10 inches from the stump in the large primary roots. Whether or not the decay in these cases was due to *Armillaria mellea* or *Fomes igniarius* could not be determined, but it is believed that it was caused by the latter fungus, as the rot in the bole of these particular trees was undoubtedly caused by *Fomes igniarius*.

Insect galleries extending for a considerable distance into the roots of aspen may be found in both young and older trees. Surrounding these galleries, a dark zone of discolored wood is found which is hard and firm and which when placed in culture did not yield a fungus. The inner surface of these galleries is also very smooth and shiny, further indicating that the discolored zone has probably been caused by the insect rather than by wood-destroying fungi.

A large number of young suckers showed discolorations—even 3- to 5-year-old suckers. In no case, however, could this discoloration be traced down into the parent root. It was always associated with an insect sting, resulting in small swellings near the base of the suckers. The insect causing these swellings and the character of the discoloration produced could be definitely determined. It is possible that this discoloration is indicative of incipient decay, resulting through the tiny branch scars common near the base of the suckers even at this early age. Similar insect stings were also commonly found on the branches near the tops of older trees, where they always caused brown discolorations near the center of the branch. This discolored wood always gave negative results in culture.

In general, then, no evidence was found to indicate that the decay caused by *Fomes igniarius* extends any appreciable distance out in the root system, or that the suckers are infected through the parent root of the old mother stump. This does not mean that infection in this manner may not be possible where *Armillaria mellea* is causing the decay. Since *Armillaria* rot in living trees was not at all common, or could not be recognized as such in Minnesota, our results neither confirm nor contradict the observations made by Eklund and Wennmark regarding *Armillaria mellea* on *Populus tremula* in Sweden.

CULTURE STUDIES

Since there is a great variation in the color of decayed aspen heartwood, it seemed desirable to attempt to determine the causal organism by cultural methods. It is, of course, an open question whether or not the three stages of decay discussed earlier in this paper are merely different stages of decay caused by the same fungus or are caused by different fungi.

The fact that fruiting bodies of *Fomes igniarius* are practically the only ones found on aspen in Minnesota points to *Fomes igniarius* as the probable cause. In only two cases were fruiting bodies of other fungi found on aspen. These were fruiting bodies of *Armillaria mellea* found near the ground line on two large, very defective trees. Both these trees also bore a large number of sporophores of *Fomes igniarius*. In all, 271 field cultures[21] were made. The results of these cultures are presented in Table XII.

TABLE XII
RESULTS OF CULTURES MADE FROM ASPEN WOOD

Stage of decay	Total cultures	Sterile cultures		Bacterial cultures		Fungus cultures	
		No.	Per cent total	No.	Per cent total	No.	Per cent total
Incipient	103	84	81.5	5	4.9	14	13.6
Intermediate	90	50	55.5	18	20.1	22	24.4
Final	49	3	6.1	..*	...	46	93.8
Dark wood of living branches	29	29	100.0	..*	...	..	...

* In two cases bacteria were present in addition to a fungus.

Inoculations from "incipient" stages are usually negative. The final stage of decay usually produces a fungous growth when cultured. These results confirm those obtained by Baxter[22] in his work on heartrot of black ash, that the hyphae of the fungus were always present inside of the black zone. On the other hand, Kauffman and Kraber[23] point

[21] The culture medium employed in this work had the following composition: distilled water 1000 cc., malt extract 25 gm., bacto-agar 15 gm.

[22] Baxter, D. V. The heartrot of black ash. *Polyporus hispidus* Fr. Papers of Mich. Acad. Sci., Arts, and Letters 3:39-50. 1923.

[23] Kauffman, C. H. and Kraber, H. M. A study of the white heartrot of locust caused by *Trametes robiniophila*. Amer. Jour. Bot. 9:493-508. 1922.

out that the mycelium of *Trametes robiniophila* Murr. may be found beyond the rot in apparently sound locust wood. Inside of the black border zone, however, they found no hyphae, but evidence of their former presence was plentiful. In our study of *Fomes igniarius* on aspen, it is apparent that the hyphae do not disappear inside of the black zone, but are present in greatest abundance in that region.

There are at least two possible explanations for the results shown in Table XII. The first is that the discoloration of heartwood is the result of an injury of almost any kind—mechanical or caused by insects, fungi, etc.—but that in only comparatively few cases it is caused by wood-destroying fungi.

The work of Münch[24] supports this explanation. He concludes that the blackened substance in such discolored wood is not the secretion of living cells, but arises only after the death of the cells, as an oxidation product of the cell contents, and that the presence of wood-destroying fungi greatly accelerates the oxidation process.

Another explanation for the large number of negative cultures may be that the discoloration is, as a rule, caused directly by wood-destroying fungi and that either the color reaction extends far beyond the point of infection or the presence of a very small number of hyphae may cause considerable discoloration. The latter explanation seems the more plausible in spite of the fact that cases were observed in which the discoloration was unmistakably the result of insect damage.

The rather common occurrence of bacteria in cultures made from the incipient and intermediate stages of decay is also of considerable interest. By the time the decay reaches the final stage, these bacteria apparently largely disappear. In only two cases were they observed in cultures made from the final stages of decay, and in both these cases a fungus was also present.

The presence of bacteria in decaying aspen wood has been previously reported by Eklund and Wennmark[25] who, in referring to certain culture experiments made by Dr. E. Melin, say in part, "It was, however, impossible to obtain cultures free from bacteria which outgrew the fungus so that it did not develop its typical characteristics. According to Dr. Melin, aspen wood is often heavily infected with bacteria."

Altho the bacteria found in connection with the decayed aspen wood were not studied microscopically, there is some reason to believe that in most cases a single organism was involved. Cloudy, slimy colonies were invariably formed on the malt agar culture medium used. Whether

[24] Münch, C. Über krankhafte Kernbildung. Ztschr. f. Forst-u. Landw. 8:533-547, 553-569. 1910.

[25] Eklund, S. and Wennmark, G. *loc. cit.*

or not these organisms play an important part in the progress of decay in aspen is a question well worth careful study.

In a way, one of the most disappointing and yet one of the most significant features of the cultural studies was the fact that it was quite impossible definitely to identify the fungi obtained by ordinary gross examination. In only a very limited number of cases were typical cultures of *Fomes igniarius* obtained. Altho most of the cultures here considered were made directly in the field, the number of contaminations was almost negligible. The fungi obtained, however, exhibited a great variation in cultural characteristics. Some grew rapidly, some grew very slowly, a few were a characteristic brown color, more a light yellow or cream color, almost every culture had some rather marked special characteristics.

The question naturally arises whether these cultures represent a large number of species of fungi or strains of one or two forms. Meinecke[26] in Utah, Eklund and Wennmark in Sweden, and others both in this country and in Europe report only three common fungi causing rots of aspen, namely, *Fomes igniarius, Armillaria mellea,* and *Fomes applanatus.* By far the most common of these three is *Fomes igniarius.*

Long and Harsch,[27] who made a very detailed study of the variation on vegetative characteristics occurring within a species of certain wood-destroying fungi, conclude that "the cultural characteristics of vegetative development of the various strains of a given species of fungus show no appreciable difference between cultures of this fungus whether obtained from infected wood or from sporophores. Neither do the hosts of the fungus seem to make any marked changes in the fundamental cultural characteristics when strains from different hosts are compared. There may be minor differences due to the host from which the strain came, but nothing more."

Schmitz,[28] on the other hand, found considerable variation both in the rate of growth and the texture of the fungus in different strains of *Fomes pinicola.* It is true that no variation in color was observed, but as the mycelium of this organism is white, variations are hardly to be expected.

In fact, it would be rather extraordinary if the wood-destroying Basidiomycetes did not show some well marked morphological and physiological variations from the normal condition. Recent work,[29]

[26] Meinecke, E. P. *loc. cit.*

[27] Long, W. H. and Harsch, R. M. Pure cultures of wood-rotting fungi on artificial media. Jour. Agr. Res. 12:33-81. 1918.

[28] Schmitz, H. Studies in wood decay V. Physiological specialization in *Fomes pinicola* Fr. Amer. Jour. Bot. 12:163-177. 1625.

[29] Leach, J. G. The parasitism of *Colletotrichum lindemuthianum.* Minn. Agr. Expt. Sta. Tech. Bull. 14. 1923. Christensen, J. J. Physiological specialization and mutation in *Helminthosporium sativum.* Phytopath. 15:785-795. 1925.

especially on the *Fungi imperfecti* and on the Basidiomycetes, show that in the species studied physiological variations are probably the rule rather than the exception.

Still more important in this connection, however, is the fact that, with two exceptions, the only fruiting bodies observed were those of *Fomes igniarius*. Trees showing the final stage of decay usually bore fruiting bodies of this fungus. Out of a total of 82 fungus cultures from 271 inoculations, 21 were typical *Fomes igniarius* and 3 exhibited doubtful characteristics. Many of the remaining cultures may be *Fomes igniarius* tho exhibiting more or less well marked variations in vegetative characteristics, and some are quite probably *Fomes applanatus, Armillaria mellea,* or other primary or secondary organisms.

HISTOLOGICAL STUDIES

Sections, 20 microns in thickness, were cut from the radial surface of blocks which formed a continuous series extending from the central portion of the final rot area outward through the black zone, intermediate and incipient stages of decay into the sound wood. Three methods of staining these sections were used: (1) Overstaining for 48 hours in an alcoholic solution of safranin, (2) Vaughan's Pianeze III b, (3) Herbert's safranin-picro analin. The best results were obtained with Herbert's stain, altho overstaining with safranin also gave excellent results. Mycelium was most commonly observed in the outer portions of the region of final rot, particularly in the black zone of *Fomes igniarius* rot. This observation agrees with the results reported by von Schrenk and Spaulding[30] who had no difficulty in finding the mycelium of *Fomes igniarius* in completely decayed wood. Kauffman and Kraber,[31] on the other hand, in their study of the heartrot of locust, did not observe hyphae in the black zone, altho they did find abundant evidence of its former presence.

That the mycelium was previously abundant in the portions of the final rot regions in our aspen samples was shown by the large number of hyphal punctures in the radial walls of the wood elements and also by the remaining scattered hyphae. These observations agree with the results obtained from the culture studies.

Outward from the black zone into the region of intermediate rot there is a marked difference in the abundance of hyphae. Mycelium was not found in any of the sections cut from wood in the incipient stage of decay. Negative results were also obtained from culture studies.

[30] von Schrenk, H. and Spaulding, P. *loc. cit.*

[31] Kauffman, C. H. and Kraber, H. M. *loc. cit.*

The filaments observed in the black zone are quite different in appearance from those observed in the typical final and intermediate stages of decay. In the vicinity of the black zone the filaments commonly run horizontally in the medullary rays and vertically in fibers. They are of relatively large diameter and branch profusely, while those in the final and intermediate stages of decay are very fine and seldom branch. This difference may be due to a difference in nutritive conditions or to different organisms.

Among the most interesting structures appearing in discolored aspen wood are the tyloses in the vessels. These are found in great abundance in all three stages of decay and there is always a very sharp, definite line between normal wood and that showing incipient decay. Are these structures caused by the fungus or are they associated with heartwood formation in aspen?

Hartig[32] states that when the wood of dicotyledonous trees is exposed by wounds the vessels become completely plugged by tyloses. Münch[33] attributes tyloses to the presence of products resulting from the process of decay which stimulate the growth and development of the parenchyma cells. Stevens[34] has described similar structures in catalpa sapwood influenced by the decay of *Polystictus versicolor* in closely neighboring tissues. In a rcent contribution by Zeller,[35] "Wood decay produced by *Trametes subrosea* has a marked influence on the neighboring sapwood. In the healthy sapwood of both peach and prune, wood tyloses are found scatteringly in the larger vessels of the spring wood only, none having been found in the smaller vessels of the summer growth. Where only three to six annual rings of sapwood separate the decayed cylinder within from the bark, tyloses were extremely numerous in the larger vessels of the spring wood in rings two or more years old. In fact, in prune wood especially, vessels of spring wood have been found nearly filled with tyloses, and tyloses were also numerous in the vessels of the summer wood. Where several annual rings separate the decayed heart and the last year's wood growth, the toxic influence of the decayed wood on the production of tyloses in vessels two or three years old is nearly as great as where the fungus is nearer."

"Such disturbances surely influence the normal physiology of a tree, bringing about a weakened framework, increasing the mortality of crop-producing wood, and causing increased susceptibility to winter injury. There are also indications that the lack of water conduction

[32] Hartig, R. The diseases of trees. Eng. Ed. London. 1894.

[33] Münch, E. Versuche über Baumkrankheiten. Naturw. Ztschr. f. Forst.—w. Landw. 8:389-408; 425-447. 1910.

[34] Stevens, N. W. *Polystictus versicolor* as a wound parasite of Catalpa. Mycologia. 4:263-270. 1912.

[35] Zeller, S. M. Brown-pocket heartrot of stone-fruit trees caused by *Trametes subrosea* Weir. Jour. Agr. Res. 33:687-696. 1926.

in wood having such an abundance of tyloses has a direct countributary bearing on the physiological disturbances in prune trees known as leaf roll, June drop of fruit, and early yellowing and dropping of leaves."

There is apparent unanimity of opinion among the investigators cited, that these tyloses are the result of the activities of wood-destroying fungi. It would be interesting to know if their presence in an infected aspen tree affects in a material way the physiology and growth of the trees.

It seems possible that the tyloses in decayed or partially decayed aspen wood may influence permeability to wood preservatives. If tyloses increase the resistance of the wood to treatment, wood intended for treatment should be intelligently selected.

Since the chemical properties of decayed aspen wood, with particular reference to its cellulose content, will be studied in detail in the near future, practically no attention was given to this phase of the problem in this study. Spaulding[36] found on *Populus* that the wood fibers of healthy wood in most cases had an inner supernumerary layer which turned blue with chlor-iodide of zinc. The rotted tissues were separated from the healthy ones by a narrow infiltrated zone. Just inside this zone of infiltrated cells the affected fibers were of very uniform thickness and the walls were decidedly thinner than those of the healthy wood where the cellulose was present. In rotted tissues the cell cavities were also larger than in the unaffected cells. In other words, the cellulose layer is more or less completely dissolved from the interior of the fibers and the secondary layer is delignified, while the cellulose skeleton is left to the last.

SUMMARY AND CONCLUSIONS

Aspen or popple (*Populus tremuloides*) is one of the most abundant and widely distributed trees in Minnesota. Its utilization, however, altho greatly on the increase, is complicated by the great prevalence of heartrot.

Three fungi are probably the cause of almost all the heartrot of aspen in Minnesota. By far the most important of these is *Fomes igniarius*. So prevalent is *Fomes igniarius* rot that it usually masks or conceals rot caused by *Armillaria mellea* and *Fomes applanatus*.

A study of 385 trees from 77 sample plots distributed throughout the range of the species in Minnesota showed that when the volume of final and intermediate rot is deducted, the mean annual growth of well stocked aspen stands on average sites culminates at about 40 years. If final rot only is deducted, the mean annual growth of aspen stands on average sites culminates at about 50 years. This seems to indicate, under

[36] Spaulding, P. Studies of the lignin and cellulose in wood. Mo. Bot. Gard. 17th Ann. Rept. 41-58. 1906.

extensive management, a pathological rotation of from 40 to 50 years for the production of mass products.

Three stages of decay were distinguished: incipient, intermediate, and final. At 70 years the total rot (i.e., incipient, final, and intermediate) affects 31.2 per cent of the merchantable volume of the tree; at 60 years 27.5 per cent, at 50 years 23.0 per cent, at 40 years 18.9 per cent, and at 30 years 14.8 per cent.

As wood affected by only incipient decay is probably not culled by any wood-using industry in Minnesota, the amount of intermediate and final rot is of greater practical importance. At 70 years the intermediate and final rot stages of decay include 20.5 per cent of the merchantable tree volume, at 60 years 15.7 per cent, at 50 years 11.4 per cent, at 40 years 7.8 per cent, and at 30 years 4.8 per cent.

If only the final stage of rot is considered, merchantable tree volume is reduced 9.1 per cent at 70 years, 4.6 per cent at 60 years, 2.4 per cent at 50 years, 1.3 per cent at 40 years, and 0.7 per cent at 30 years.

Branch scars are probably the most important avenues of entrance for wood-destroying fungi, but fire scars and insect injuries are undoubtedly contributing factors.

No evidence was found to prove that suckers are infected by the parent stump through the roots. Heartrot seldom extends any appreciable distance into the roots, but usually terminates in the base of the stump.

Two hundred and seventy field cultures made from decayed aspen wood showed that a fungus may usually be obtained from the final stage of decay. Bacteria were commonly obtained from the intermediate stage, while 85.5 per cent of the cultures made from wood showing incipient decay were negative.

Microscopic examination of decayed aspen wood shows the mycelium of fungi to be abundant in the black rings characteristic of the final stage of decay. Mycelia of fungi are also common inside of these rings, but rarely are they found very far outside of them (i.e., in the intermediate stage). Mycelium was not found in the incipient stage of decay in any of the microscopic sections examined.

The results of these studies indicate that if aspen is grown with adequate protection from fire on a 40- to 50-year rotation under average Minnesota conditions, decay will not be a very serious factor in its production.

630.72 M66B NO 33 50

a39001 007401295b